RISK ASSESSMENT

KESTERSON PROGRAM

U.S. Bureau of Reclamation
Mid-Pacific Region

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RISK ASSESSMENT

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SUMMARY

This risk assessment of Kesterson Reservoir (KR) cleanup alternatives consists of four elements:

- Contamination evaluation and determination of contaminants of concern

- Analysis of exposure pathways, identification of key species, and estimates of contaminant transfer between pathway components

- Review of toxicological properties of contaminants of concern for key species

- Risk characterization, including the range of magnitude of expected exposure and the likelihood of such exposure occurring for each cleanup alternative

Review of information related to past and present contamination at KR indicates that selenium is a major contaminant of concern because, in the past, it has exceeded water quality guidelines and criteria, has accumulated in KR soils, has migrated into the groundwater in some locations, and has been linked experimentally and observationally to wildlife effects.

Other identified constituents of possible concern which have exceeded water quality guidelines and criteria include boron, chromium, molybdenum, mercury, salts, and zinc. Chromium, mercury, molybdenum, and zinc are not of concern because these constituents neither appear in KR soils above background concentrations, nor exceed guidelines and criteria for KR groundwater supplies. TDS is not of concern because no evidence exists that TDS concentrations in groundwater supplies will cause adverse wildlife effects in KR. Boron is not of concern because no existing evidence has linked boron to observed KR wildlife effects; such evidence does exist for selenium.

Three cleanup alternatives were analyzed in detail: the Flexible Response Plan (FRP), the Onsite Disposal Plan-1 (excavating about 450,000 cubic yards), and the Onsite Disposal Plan-2 (excavating about 1,000,000 cubic yards).

Potential exposure pathways, resulting from implementation of these alternatives, to residual contamination at KR include food chain or ingestion, direct contact and absorption, and air migration and inhalation. Populations potentially exposed to contamination via these pathways include human populations (foragers, adjacent residents, workers and

hunters) and various fish and wildlife species. Insufficient information exists to perform a quantitative risk assessment for potentially exposed human populations at KR. A qualitative risk assessment for human populations is presented in the Kesterson Program EIS (USBR, 1986a). Food chain exposure is considered the most important exposure pathway for fish and wildlife at KR.

Key fish and wildlife species were identified for quantitative risk assessment to represent the range of possible exposure impacts at KR. Selection of species was based on several considerations: they are the terminus of a major KR food chain exposure pathway, impacts on species have been observed in the past, they are rare or endangered species, they have particularly sensitive life stages, or information is available on the effects of selenium exposure for the species.

Key species identified were the mallard, American coot, black-necked stilt, tricolored blackbird, mosquitofish, eared grebe and San Joaquin Valley kit fox. These species represent potential exposure to contamination via the midwater, benthic, aquatic rooted plant, fish, and terrestrial pathways. Detailed food chain exposure diagrams for each of these species were abstracted into simplified selenium transfer models. These models were used with a "Monte Carlo" simulation technique to estimate the probability distribution of predictions of selenium concentration in the diets of the key species.

Use of this modeling approach has several limitations. The model assumed a constant and steady state relationship between selenium levels in exposure pathway components and does not take into account the length of time necessary to achieve steady state conditions. Also, because insufficient information exists to develop quantitative dose response relationships for diet selenium exposure for the key species at KR, the model results cannot be used to make quantitative estimates of the impact of cleanup alternatives on the exposed populations.

A review of the toxicological effects of selenium indicates the following diet selenium concentrations may result in harmful impacts:

Key Species Group	Harmful Diet Selenium Concentration (mg/kg)	Diet Cleanup Goals (mg/kg)
Birds	5-10	3
Mammals	2-5	--
Fish	3-5	5

These harmful effect ranges are different than cleanup goals because they represent the range of selenium concentrations where harmful effects have been observed rather than more conservative cleanup goals.

The harmful effect levels and cleanup goals are compared to the model predictions of diet selenium levels to evaluate the potential for success of the alternative cleanup plans. Figures S-1 through S-3 and Table S-1 show the results.

The risk characterization does not indicate that any of the plans will clearly fail. For avian species, the results for the FRP show that 40 to 65 percent of the diet selenium predictions show levels below the harmful effect range. The Onsite Disposal Plan-1 shows a greater frequency of below harmful effect predictions, 65 to 90 percent. The Onsite Disposal Plan-2 results in the highest frequency of below harmful effect predictions, 85 to 95 percent.

The risk characterization results show that each of the plans may present some risks to wildlife. Based on the methods and assumptions used for the risk characterization, predicted risks are greatest for the FRP, less for Onsite 1, and least for Onsite 2.

Termination of drainwater flow and implementation of the FRP may reduce avian diet selenium concentrations to 8 mg/kg (below the top of the harmful effects range) at a relatively low first-year cost ($2.5 million); 50 percent of the diet selenium predictions indicate this result. Increased expenditures ($20 million in first-year costs) for the Onsite Disposal Plan-1 may reduce avian diet selenium concentrations to 4 mg/kg (below the bottom of the harmful effects range), as indicated by 50 percent of the predictions. Greater expenditures ($40 million in first-year costs) for the Onsite Disposal Plan-2 may reduce avian diet selenium concentrations to 2.5 mg/kg (below the cleanup goal of 3 mg/kg) as indicated by 50 percent of the predictions. To achieve a greater probability (90 to 95 percent) that the cleanup goal of 3 mg/kg will be achieved, further excavation of KR would be necessary, at a cost of up to $144 million.

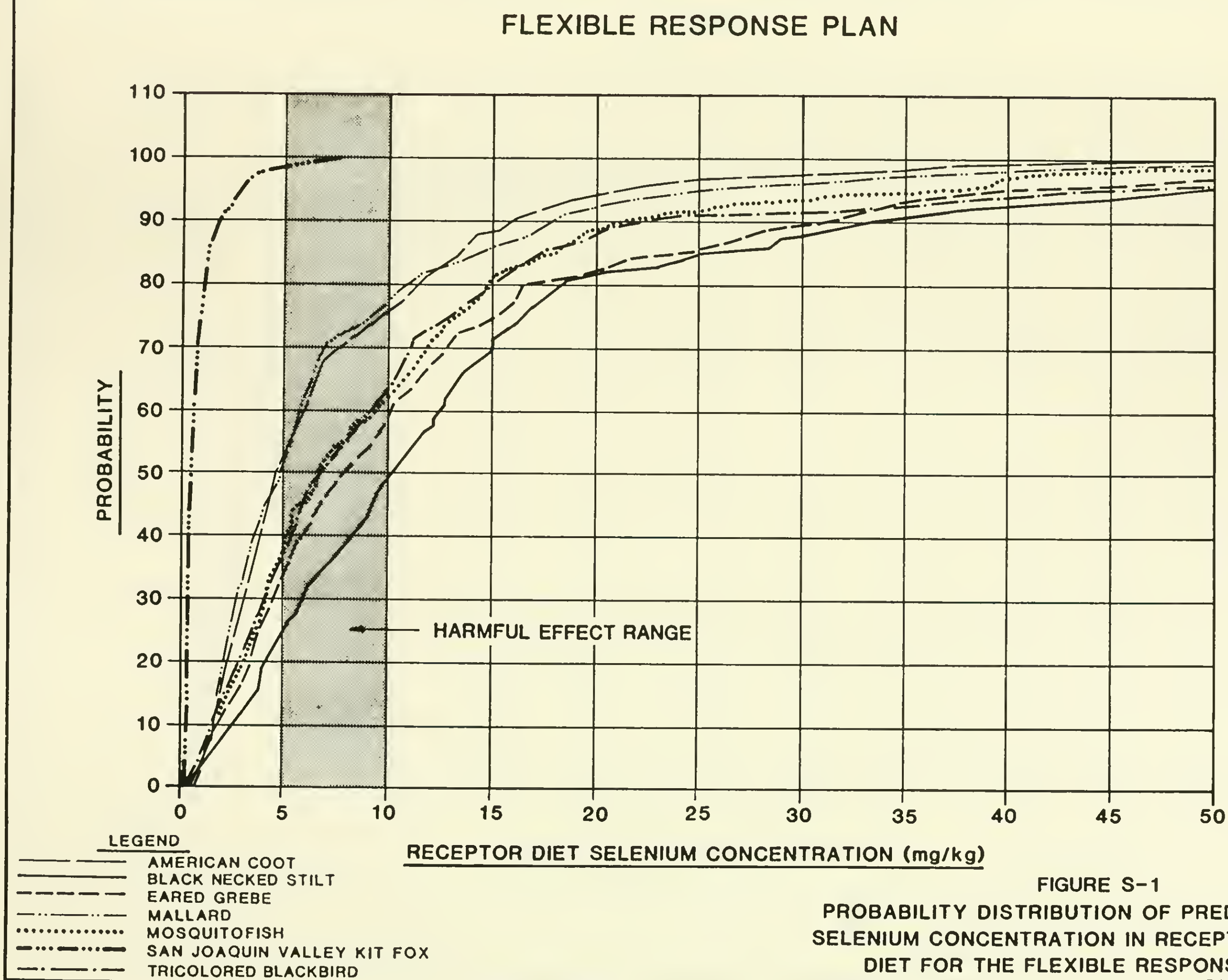

FIGURE S-1
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

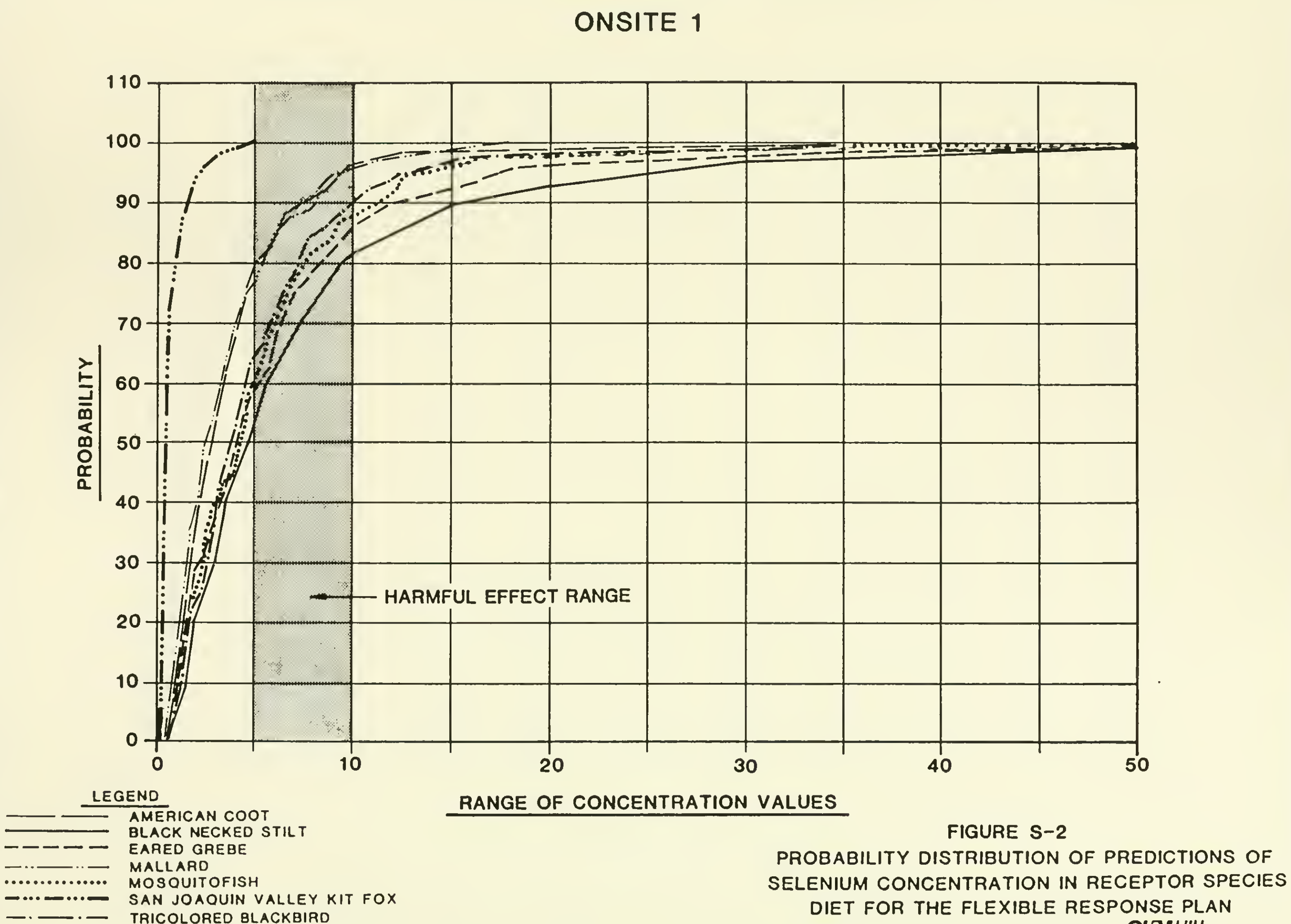

FIGURE S-2
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

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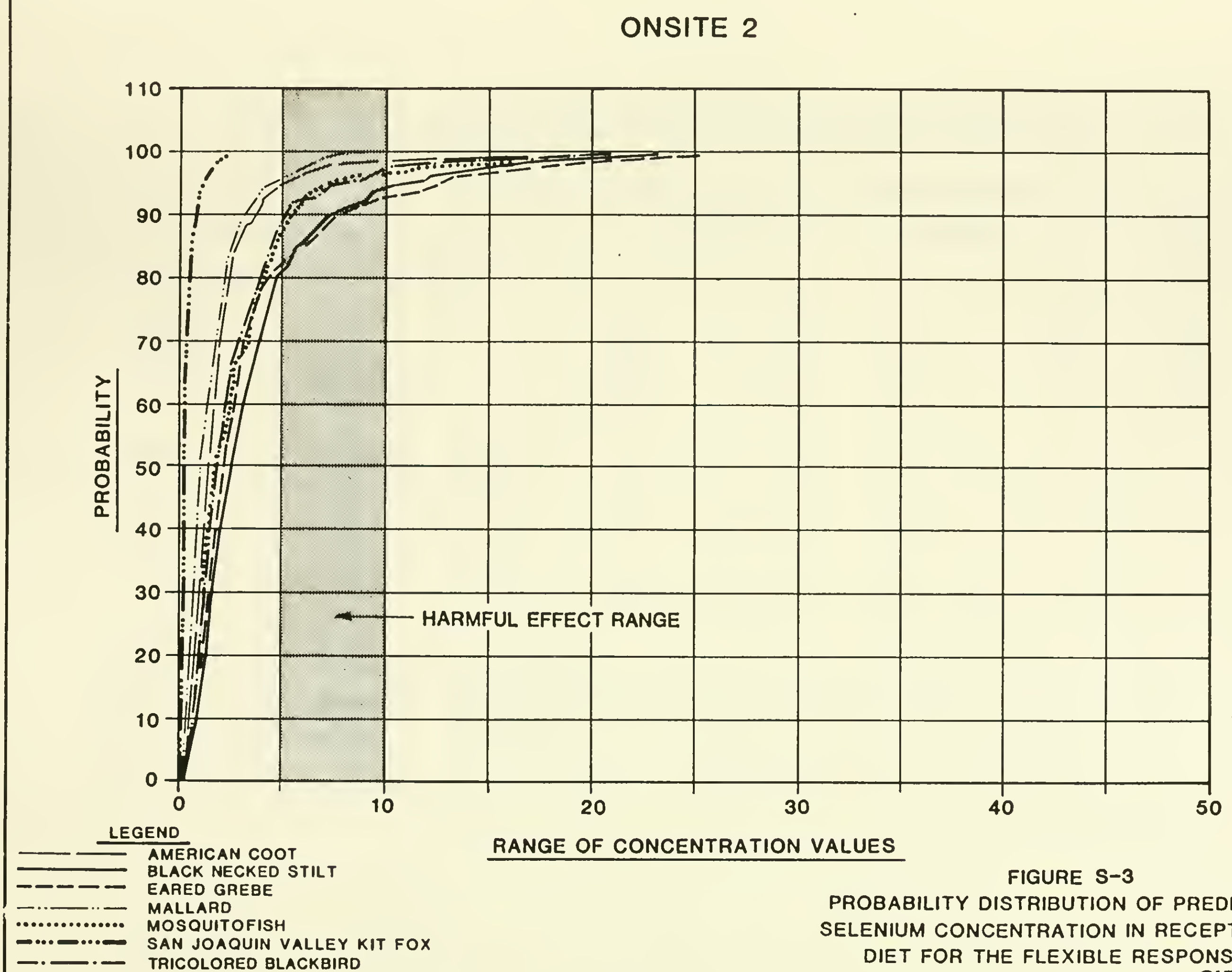

FIGURE S-3
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

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Table S-1
PERCENT OF DIET SELENIUM PREDICTIONS THAT ARE BELOW ESTIMAED HARMFUL LEVELS FOR EACH KEY SPECIES AND FOR EACH CLEANUP ALTERNATIVE

	Cleanup Alternative					
Key Species	FRP		Onsite-1[c]		Onsite-2[d]	
Birds - Harmful Effect Level[a]	5	10	5	10	5	10
Mallards	50	80	75	95	95	~100
Coots	50	75	80	95	95	~100
Blacknecked Stilts	25	50	50	80	80	95
Tricolored Blackbirds	35	65	60	90	85	95
Eared Grebes	35	60	60	85	80	90
Mammals - Harmful Effect Level[a]	2	5	2	5	2	5
San Joaquin Valley Kit Fox	90	~100	95	~100	~100	~100
Fish - Harmful Effect Level[a,b]	3	5	3	5	3	5
Mosquitofish	20	35	35	50	70	90

[a]Diet selenium concentration (mg/kg).

[b]Mosquitofish not harmed by these selenium levels although other species may be.

[c]450,000 cubic yards.

[d]1,000,000 cubic yards.

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Chapter 1
APPROACH

INTRODUCTION

The overall objective of this risk assessment is to provide, to the extent feasible with existing information, a quantitative analysis of the magnitude and uncertainty of estimates of potential adverse impacts on fish, wildlife, and human populations that may result from implementation of Kesterson Reservoir (KR) cleanup alternatives.

The risk assessment contains the following components:

- Contamination evaluation and determination of contaminants of concern
- Analysis of exposure pathways, identification of key species, and estimates of transfer factors between pathway components
- Review of toxicological properties of contaminants of concern for key species
- Risk characterization, including the range of magnitude of expected exposure and the likelihood of such exposure occurring for each disposal alternative

CONTAMINATION EVALUATION

The purpose of the contamination evaluation is to determine potential constituents of concern and the extent of their distribution at KR. Previous contamination evaluations for KR are reviewed and summarized. This evaluation includes a review of existing literature for evidence of the effects of contaminants at KR.

EXPOSURE ASSESSMENT

The objectives of this component are to identify the major contamination exposure pathways at KR; the key fish, wildlife, and human populations which are receptors of contamination from these pathways; the size of the exposed populations; and to estimate transfer factors and their uncertainties, which describe contamination transport between exposure pathway components.

TOXICITY ASSESSMENT

The objectives of the toxicity assessment are to determine the nature and extent of effects associated with exposure to contamination. It is a two-step process consisting of toxicological evaluation and dose-response assessment.

The toxicological evaluation is a qualitative analysis of scientific data to determine the nature and severity of actual or potential environmental risk associated with exposure to contamination. It results in a toxicity profile which presents a review of the literature on the types of adverse effects manifested, the doses employed, and the routes of exposure.

The dose-response assessment is an attempt to make a quantitative estimate of impact from exposure to a toxic chemical. It defines the relationship between the dose of a chemical and the expected incidence of the adverse effect.

RISK CHARACTERIZATION

Risk characterization is the process of estimating the potential adverse environmental effect, using the results of the toxicity assessment, under the various conditions of exposure defined in the exposure assessment.

Uncertainty related to the variability of bioaccumulation relationships and diet distribution are evaluated using a Monte Carlo simulation procedure.

This procedure allows:

- Estimation of the expected range of exposure levels given the variability of environmental conditions and the uncertainty of transfer and diet factors

- Evaluation of the conceptual exposure pathway model regarding error due to poor estimates of input parameters, as well as the sensitivity of the model to particular parameters

The Monte Carlo simulation procedure provides estimates of the range of predictions of contaminant exposure for each of the key species and cleanup alternatives.

Chapter 2
CONTAMINATION EVALUATION

INTRODUCTION

The source of contamination at KR is subsurface drainwater from irrigated agricultural lands that was delivered to KR via the San Luis Drain (SLD). Delivery of drainwater ceased in June 1986. Contamination which remains at KR is that portion of contaminants delivered via drainwater that has accumulated in soils and biota. It is also possible that contaminants that have seeped into the shallow groundwater beneath KR could be reapplied to the surface of KR as part of water supply for the Flexible Response Plan (FRP) cleanup alternative (see Chapter 3).

The California State Water Resources Control Board (SWRCB) has identified constituents of concern in agricultural drainwater (SWRCB 1986). These constituents are shown in Table 2-1 and are used as a basis for further evaluation of KR contaminants. The levels of these contaminants in SLD drainwater, KR surface water, KR groundwater, KR soils, and biota are evaluated to determine if there is any evidence for residual contamination that has accumulated in KR soils, biota, or groundwater that may result in future harmful effects to potentially exposed populations.

PAST WATER CONTAMINANT CONCENTRATIONS

Table 2-1 summarizes water quality guidelines and criteria established for the SWRCB constituents of concern (USBR 1986a). Table 2-2 is a summary of SLD drainwater quality during 1984 and 1985 (USBR 1985). Table 2-3 summarizes KR surface water quality during 1984 and 1985 (USBR 1985). Table 2-4 shows KR shallow groundwater quality during 1984 and 1985 (USBR 1986a). The following drainwater constituents have exceeded water quality guidelines and criteria in historic SLD drainwater and KR surface water, and therefore warrant further analysis: boron, chromium, molybdenum, mercury, TDS, selenium, and zinc.

BORON

Boron was present in agricultural drainwater delivered to KR at concentrations ranging from 13,000 to 17,000 µg/l while boron concentrations in the surface water at KR have been in range of 11,000 to 65,000 µg/l. These data show that boron levels increased in some areas probably due to evaporation in KR surface water.

Table 2-1
WATER QUALITY GUIDELINES AND CRITERIA FOR
SWRCB DRAIN WATER CONSTITUENTS OF CONCERN

SWRCB Constituents of Concern[a] (μg/l)	Water Quality Guidelines and Criteria (μg/l): Ambient Water Quality Criteria To Protect Fresh-Water Aquatic Life[b]		Drinking Water[c]		
	4-Day Average	1-Hour Average	Primary	Secondary	Other
Boron	--	--	--	--	750[g]
Cadmium	6.9	52.7	10	--	--
Chromium	11	16	50	--	--
Copper	84.6	155.2	--	1,000	--
Manganese	--	--	--	--	--
Mercury	0.012	2.4	2	--	--
Molybdenum	--	--	--	--	70[i]
Nickel	160[d]	527[f]	--	--	--
Selenium	35[d,e]	260[f]	10[h]	--	--
Zinc	47[d]	570[f]	--	5,000	--
TDS (mg/l)	--	--	--	1,000	--

[a]SWRCB 1986.

[b]EPA 1985a. Total recoverable metals, value not to be exceeded more than once every 3 years on the average.

[c]EPA 1979.

[d]EPA 1980a. 24-hour average not 4-day average. The selenium criterion is currently being reviewed, and could be lowered to 2-5 mg/l.

[e]Selenium as inorganic selenite.

[f]EPA 1980a. Maximum value not one-hour average.

[g]EPA 1980b. For long-term irrigation on sensitive crops.

[h]EPA 1985b. This criterion is currently being reviewed and could be raised to 45 μg/l.

[i]EPA 1980a. Ambient water quality goal for human health.

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Table 2-2
SAN LUIS DRAIN CONSTITUENTS OF CONCERN AT CHECK 2
(1984-1985)

Date Sampled	EC µmhos/cm	B ug/l	Cd ug/l	Cr ug/l	Cu ug/l	Hg ug/l	Mn ug/l	Mo ug/l	Ni ug/l	Se ug/l	Zn ug/l
84/03/12	11200	15000	<1	30	6	<.1	270	110	10	300	20
84/04/02	11600	14000	<1	23	4	<.1	60	100	9	400	20
84/04/24	12100	13000	<1	21	4	<.1	30	98	9	350	30
84/05/21	12380	14000	1	10	3	<.1	70	140	27	420	20
84/06/18	12580	14000	<1	9	5	<.1	30	120	8	330	20
84/07/23	12490	15000	<1	22	<20	<.1	<10	74	21	340	<5
84/08/20	12250	16000	<1	12	<20	<.1	11	28	30	350	12
84/09/24	12200	16000	<1	9	2	<.1	40	69	<1	360	10
84/10/10	13240	17000	<1	12	4	<.1	30	130	51	370	<10
84/11/12	10980	15000	2	4	2	<.1	100	110	6	250	20
84/12/10	10800	15000	<1	7	3	<.1	700	110	18	230	<10
85/01/14	9720	13000	<1	10	2	<.1	330	110	22	320	<10
85/02/13	9140	12000	<1	11	3	<.1	330	94	13	280	20
85/03/14	11030	12000	1	12	5	<.1	190	120	13	200	<10
85/04/09	11780	13000	<1	8	3	0.2	50	120	10	9	20
85/05/08	13220	15000	1	10	5	3.0	60	120	8	320	10
85/06/06	12970	15000	<1	11	5	0.3	40	110	22	410	10
85/07/11	12300	16000	-	-	-	-	-	-	-	350	-
85/08/08	11670	15000	-	10	2	1.0	-	51	17	-	-
85/09/12	11280	-	-	-	-	-	-	-	-	-	-

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Table 2-3
KESTERSON RESERVOIR CONSTITUENTS OF CONCERN AT
SURFACE WATER SITES (1984-85)

Site Name	Date Sampled	EC µmhos/cm	B ug/l	Cd ug/l	Cr ug/l	Cu ug/l	Hg ug/l	Mn ug/l	Mo ug/l	Ni ug/l	Se ug/l	Zn ug/l
KR1/2	84/03/12	11200	13000	<1	9	3	<.1	50	90	2	500	20
KR1/2	84/04/02	11700	14000	<1	12	4	<.1	10	110	11	300	20
KR1/2	84/04/23	12300	15000	<1	4	2	<.1	20	140	11	170	20
KR2/5	84/05/18	12640	14000	<1	12	2	<.1	40	170	11	370	50
KR2/5	84/06/13	12740	15000	<1	14	3	<.1	30	120	34	2	<10
KR2/5	84/07/10	12900	15000	<1	5	<20	<.1	10	150	20	390	20
KR2/5	84/08/08	12520	17000	<1	12	<20	<.1	17	60	26	320	<5
KR2/5	84/09/19	12800	16000	<1	9	<20	<.1	13	200	9	390	<5
KR2/5	84/10/30	12940	18000	<1	6	2	<.1	20	150	19	380	20
KR2/5	84/11/26	10700	15000	<1	10	4	<.1	130	120	9	250	20
KR2/5	84/12/18	1110	16000	<1	9	2	0.2	460	120	5	290	<10
KR2/5	85/01/23	-	-	<1	16	15	-	-	-	11	270	-
KR2/5	85/01/29	10090	11000	<1	19	5	<.1	300	110	22	250	40
KR2/5	85/02/26	10110	13000	<1	18	5	0.6	150	86	14	270	<10
KR2/5	85/03/26	10880	13000	<2	-	5	<.1	50	110	12	270	<10
KR2/5	85/04/22	11900	14000	2	10	4	<.1	90	130	19	310	10
KR2/5	85/05/22	12400	15000	<1	8	7	<.1	50	110	-	260	<10
KR2/5	85/06/18	12310	15000	<1	12	2	0.2	50	120	12	430	20
KR2/5	85/07/23	12700	16000	-	-	-	-	-	-	-	370	-
KR2/5	85/07/23	12700	-	-	-	-	-	-	-	-	-	-
KR2/5	85/08/20	12030	-	-	-	-	-	-	-	-	-	-
KR5/6	84/03/12	11300	14000	<1	7	3	<.1	20	90	<1	300	20
KR5/6	84/04/02	11700	14000	<1	8	3	<.1	<10	94	12	300	20
KR5/6	84/04/23	12400	14000	<1	6	1	<.1	20	150	9	270	20
KR5/6	84/05/17	13840	15000	1	4	2	<.1	20	190	11	460	80
KR5/6	84/06/13	15640	19000	<1	2	3	<.1	40	170	13	330	10
KR5/7	84/06/13	14820	18000	<1	5	2	<.1	40	160	15	390	10
KR5/7	84/07/10	15720	18000	<1	2	<20	0.1	40	170	23	370	<5
KR5/7	84/08/08	14410	18000	<1	<1	<20	<.1	29	72	34	340	<5
KR5/7	84/09/20	14870	19000	<1	1	-	<.1	-	200	16	330	-

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Table 2-3
(Continued)

Site Name	Date Sampled	EC µmhos/cm	B ug/l	Cd ug/l	Cr ug/l	Cu ug/l	Hg ug/l	Mn ug/l	Mo ug/l	Ni ug/l	Se ug/l	Zn ug/l
KR5/7	85/01/23	-	-	<1	8	11	-	-	-	8	190	-
KR5/7	85/01/28	10012	13000	<1	12	4	<.1	20	110	21	250	<10
KR5/7	85/02/26	10960	14000	<1	8	5	0.2	50	100	14	130	20
KR5/7	85/03/27	11320	13000	1	2	17	<.1	20	120	13	170	10
KR5/7	85/05/21	13920	17000	1	2	2	0.1	30	170	9	300	10
KR5/7	85/06/18	14570	18000	<1	6	2	0.1	30	180	8	320	20
KR5/7	85/07/25	14230	18000	-	-	-	-	-	-	-	310	-
KR6/8	84/05/17	15250	18000	<1	<2	4	<.1	30	170	67	200	30
KRP03	84/03/12	11400	14000	<1	3	3	<.1	20	100	6	200	20
KRP03	84/06/13	17970	21000	<1	2	3	0.1	40	210	17	78	30
KRP03	84/07/10	24600	29000	<1	<1	<20	<.1	20	210	21	110	<5
KRP03	84/08/08	32620	43000	<1	4	<20	0.1	56	120	23	28	21
KRP03	84/09/21	56490	65000	<1	<1	<20	0.1	59	540	6	24	7
KRP03	85/01/23	-	-	<1	4	6	-	-	-	9	190	-
KRP03	85/01/30	15160	21000	<1	2	3	<.1	20	150	10	190	70
KRP03	85/02/27	1590	22000	<1	2	5	0.3	30	130	12	67	20
KRP03	85/03/25	15650	22000	<1	-	1	<.1	30	110	8	82	<10
KRP03	85/04/22	16480	21000	<1	5	3	<.1	50	48	7	33	20
KRP03	85/05/21	19580	28000	<1	1	3	0.2*	50	130	16	53	20
KRP04	85/01/23	-	-	<1	3	5	-	-	-	8	140	-
KRP06	84/06/13	19110	24000	<1	1	3	<.1	40	160	21	270*	20
KRP06	84/07/10	25740	32000	<1	2	<20	<.1	40	220	20	74	7
KRP06	84/08/08	11480	54000	<1	3	<20	<.1	28	190	20	54	<5
KRP06	85/01/23	-	-	<1	3	11	-	-	-	7	140	-
KRP06	85/04/24	19600	27000	<1	1	3	<.1	40	210	20	140	30
KRP06	85/05/21	24800	35000	1	2	1	<.1	90	180	9	70	50
KRP08	84/05/17	15920	20000	<1	2	2	0.1	130	140	36	140	40
KRP08	85/01/29	13180	19000	<1	4	2	0.3	20	180	30	190	20
KRP08	85/02/26	14440	21000	<1	1	5	<.1	40	160	9	130	30
KRP08	85/04/24	19480	26000	<1	<1	2	<.1	90	130	15	3	30
KRP08	85/05/21	27300	41000*	<1	1	1	0.2*	180*	140	12	69*	30

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Table 2-3
(Continued)

Site Name	Date Sampled	EC µmhos/cm	B ug/1	Cd ug/1	Cr ug/1	Cu ug/1	Hg ug/1	Mn ug/1	Mo ug/1	Ni ug/1	Se ug/1	Zn ug/1
KRP09	84/03/12	13600	17000	<1	3	4	0.2	80	75	<1	130	160
KRP09	85/01/30	12400	15000	<1	7	2	<.1	20	110	40	230	30
KRP09	85/02/26	7600	16000	<1	7	3	0.2	20	130	10	210	20
KRP09	85/03/27	11940	16000	<1	<1	3	<.1	30	140	9	200	<10
KRP09	85/04/24	13090	17000	2	2	3	<.1	30	150	8	90	20
KRP09	85/05/21	15990	22000	<1	2	2	<.1	50	150	9	220	10
KRP09	85/06/19	21100	29000	<1	<1	2	<.1	50	240	16	98	20
KRP09	85/07/25	>20000	33000	-	-	-	-	-	-	-	110	-
KRP12	84/03/12	12100	15000	<1	2	2	<.1	60	110	3	70	20
KRP12	84/04/23	16000	22000	<1	4	3	<.1	70	100	11	50	20
KRP12	84/05/17	23800	27000	<1	2	5	<.1	60	160	120*	64	60
KRP12	85/01/30	13580	19000	<1	8	2	0.3	20	140	26	140	60
KRP12	85/03/27	12900	17000	<1	11	5	<.1	30	160	7	240	10
KRP12	85/04/24	17670	26000	1	1	4	<.1	30	170	18	7	20

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Table 2-4
KESTERSON RESERVOIR SHALLOW GROUNDWATER
CONSTITUENTS OF CONCERN
(1984-1985)

Constituent (μg/l)	Monitoring Data[a] (μg/l) — USBR Monitoring Well Data, March 1984 - November 1985			
	Background Wells		Kesterson Reservoir	
	No. Obser.	Average	No. Obser.	Average
Boron	56	3,076	655	14,000
Cadmium	55	1.1	599	1.3
Chromium	58	5.8	651	9.5
Copper	49	3.3	581	9.9
Mercury	51	0.11	610	0.13
Manganese				
Molybdenum	54	14.2	657	59.2
Nickel	56	10.6	647	30.3
Selenium	60	1.8	817	9
Zinc	32	56.5	453	78
TDS[b] (mg/l)	62	4,000	883	10,900

[a]Values less than detection limit set equal to detection limit to calculate averages. Data for steel-cased wells are not included for zinc.

[b]TDS for monitoring wells estimated by multiplying electroconductivity by 0.8.

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Concentrations of boron in the shallow groundwater beneath KR average 14,000 μg/l or about the same concentrations as in the surface water.

CHROMIUM

Agricultural drainwater delivered to KR contained 4 to 30 μg/l of chromium. KR surface water samples showed levels from less than 1 to 19 μg/l. The difference in concentrations between SLD drainwater and KR surface water indicates that chromium may be removed from the water column. The concentrations of chromium in the shallow groundwater beneath KR are approximately equal to surface water at KR, showing that chromium is not removed from water as it seeps through the soil into the ground.

MERCURY

Levels of mercury in drainwater varied from less than 0.1 to 3 μg/l. Levels up to 0.6 μg/l have been found in KR surface water. The level of mercury in shallow groundwater beneath KR was 0.13 μg/l, approximately equal to background concentrations of 0.11 μg/l.

MOLYBDENUM

Molybdenum in SLD water delivered to KR ranged from 28 to 140 μg/l. Surface water molybdenum concentrations at KR ranged from 48 to 540 μg/l, indicating molybdenum concentrations increased probably due to evaporation in KR surface water. Molybdenum concentrations in groundwater beneath KR is lower than KR surface water, indicating that molybdenum may have been removed in soil as surface water seeped into the ground.

SALTS

Agricultural drainwater delivered to KR contained 4,992 to 10,896 mg/l of total dissolved solids (TDS). Surface water samples from ponds at KR showed TDS levels 1,272 to 16,880 mg/l, indicating an increase in concentrations probably due to evaporation.

SELENIUM

Levels of selenium in SLD drainwater averaged approximately 300 μg/l.

Levels of selenium in KR surface water decreased from south to north, suggesting that selenium was removed from the water column, probably by chemical or biological processes (LBL, 1986).

Selenium concentrations in the shallow groundwater beneath KR are much lower than in KR surface water, also suggesting selenium is being removed in KR soils and sediments.

ZINC

Concentrations of zinc in the shallow groundwater beneath KR are similar to those historically found in KR surface water, suggesting that zinc has seeped into the groundwater and has not accumulated in KR soils.

PRESENT SOIL AND WATER SUPPLY CONTAMINANT CONCENTRATIONS

Table 2-5 shows constituents of concern levels in KR soils (USBR 1986a). No nearby KR wetland soil background levels for these contaminants, except for selenium, have been identified. Table 2-5 also shows expected constituent concentration in San Joaquin Valley soils similar to those underlying KR. Selenium is the only constituent which exceeds either background levels or San Joaquin Valley soils levels.

Table 2-6 shows the quality of groundwater based on analyses of existing water supply which will be applied to KR with implementation of FRP. Boron and TDS (0.8 x EC) are the constituents of concern which exceed water quality guidelines and criteria.

BIOTA

BACKGROUND

Mosquitofish (*Gambusia affinis*) captured at KR in May 1982 were found to have high levels of selenium (about 135 ppm - Saiki 1986). Because of these findings, the U.S. Fish and Wildlife Service (USFWS) began intensive studies at KR and at Volta Wildlife Area (a control area 10 km to the southwest which receives surface water) to further define the effects and extent of contamination resulting from drainwater application to KR.

In 1983, samples collected by USFWS included tissues and eggs of American coots, ducks, eared grebes (*Podiceps nigricallis*), and black-necked stilts (*Himantopus mexicanus*). These samples were analyzed for selenium, arsenic, cadmium, mercury, lead, zinc, and silver. Elements other than selenium were found in similar concentrations in the samples from KR and the Volta control site. Samples of food chain components, including rooted plants, invertebrates, and mosquitofish, were also collected at both sites in 1983. These samples were analyzed for silver, arsenic, boron, cadmium, chromium, copper, mercury, molybdenum, nickel, lead, selenium, and zinc. Only total selenium and boron concentrations were significantly higher in food chain samples collected at KR than in those collected at Volta Wildlife Area (Ohlendorf, et al. 1986).

Table 2-5
SUMMARY OF SOIL CONCENTRATIONS (MG/KG) OF
CONSTITUENTS OF CONCERN

Constituent	San Joaquin Valley Background Soils[a] Min.	Max.	Mean	Kesterson Soils and Sediments[b] Min.	Max.	Mean
Boron	NDA	NDA	NDA	LD	LD	LD
Cadmium	LD	2	2	LD	LD	LD
Chromium	LD	770	66	25	160	53
Copper	LD	160	23	4	33	14
Manganese	LD	2,300	660	210	880[c]	434
Mercury	LD	9.4	.07	LD	LD	LD
Molybdenum	LD	28	2.1	LD	10	3
Nickel	LD	160	37	9	120	34
Selenium	LD	2.8	.24	LD	85	7
Zinc	LD	140	70	13	100[d]	NDA

[a]Ron Tidball, USGS, unpublished data.

[b]USBR (1986a)

[c]One sample out of 157 had 2,600 mg/kg Mn.

[d]One sample had 220 mg/kg and one sample had 230 mg/kg out of 157 samples.

Notes: LD = Less than analytical detection limit.
NDA = No data available.
Means calculated not including values less than detection.

Table 2-6
QUALITY OF GROUNDWATER TO BE APPLIED TO KESTERSON RESERVOIR UNDER FRP

Site Name	Date Sampled	EC Umhos/cm	As µg/L	Se µg/L	Cr µg/L	Cu µg/L	Mo µg/L	Ni µg/L	Zn µg/L	B µg/L	Ca Mg/L	Mg Mg/L
Well #1	07/09/86	10160	3	<1	3	<4	14	<4	<10	4000	340	310
Well #1	07/15/86	10600	3	<1	<2	<4	16	<4	<10	4000		
Well #1	07/24/86	10940	3	<1	<2	<4	24	<4	<10	5000	370	340
Well #1	07/31/86	11320	3	<1	<2	<4	20	<5	<10	5000	360	330
Well #1	08/06/86	11290	3	<1	<2	<4	24	<4	<10	5000	360	330
Well #1	09/29/86	11790	3	<1	<2	<4	21	<5	<10	6000	370	340
Well #2	07/09/86	6210	2	<1	<2	<4	5	<4	<10	1900	200	160
Well #2	07/15/86	5820	2	<1	<2	<4	7	<4	<10	1800		
Well #2	07/24/86	6000	2	<1	<2	<4	9	<4	<10	2000	200	160
Well #2	09/29/86	6160	2	<1	<2	<4	8	<5	<10	1500	200	160
Well #3	07/09/86	4830	1	<1	<2	<4	<4	<4	<10	700	250	120
Well #3	07/15/86	4850	1	<1	<2	<4	<4	<4	<10	800		
Well #3	07/24/86	4990	1	<1	<2	<4	<4	<4	<10	800	160	130
Well #3	08/06/86	5150	1	<1	<2	<4	24	<4	<10	800	160	130
Well #3	09/29/86	6250	1	<1	3	<4	14	<5	<10	1700	190	140
Well #4	07/09/86	6140	1	<1	<2	<4	12	<4	<10	1800	190	140
Well #4	07/15/86	6170	1	<1	<2	<4	12	<4	<10	200		
Well #4	07/24/86	6350	1	<1	<2	<4	11	<4	<10	2000	210	160
Well #4	07/31/86	6520	1	<1	<2	<4	12	<5	<10	2000	210	150
Well #4	08/06/86	6530	1	<1	<2	<4	14	<4	<10	2000	210	160
Well #4	09/29/86	5280	1	<1	<2	<4	<4	<5	<10	800	170	36
Well #5	09/29/86	6670	1	<1	<2	<4	11	<5	<10	2200	230	160
Well #6	09/29/86	5320	2	<1	<2	<4	6	<5	<10	1000	150	120
Well #7	09/29/86	6320	<1	<1	<2	<4	13	<5	<10	2100	190	140
Well #8	09/29/86	7460	<1	<1	5	<4	10	<5	10	2800	250	190

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Boron found in vegetation at KR tends to concentrate in leaf tips where it is available to browsing animals (Gupta et al. 1985). Few data are available, however, concerning the acute and chronic toxicity of boron to fish and wildlife. Boron compounds (boric acid and borax) have been shown to cause mortality and teratogenic development when injected into eggs (Landauer 1952, Birge and Black 1977).

In 1983, researchers concluded that selenium was the most likely cause of avian deaths and deformities at KR because the types of deformities found in avian embryos and young were typical of those induced by exposure to high levels of selenium, and selenium concentrations in the samples greatly exceeded those found in other areas of the United States (USDI 1984). Thus, selenium has been identified as the principal contaminant of concern at KR.

The importance of selenium as a contaminant at KR is increased because of the likelihood of bioaccumulation. Studies by Lemly (1985) in an aquatic ecosystem indicated that plankton (zooplankton and phytoplankton combined) concentrated selenium to 750 times the concentration in the water of Belews Lake, North Carolina, and that fish contained selenium concentrations 4,000 times that in water. In addition, sediments contained 350 times and benthic invertebrates contained 1,050 times the selenium concentrations of water in the lake. Selenium in water is taken up by biota including marsh plants, phytoplankton, zooplankton, and insects that contribute to the diets of higher forms of wildlife in the area (Burau 1985). Bioaccumulation has also been documented at KR (Ohlendorf, et al. 1986).

INVERTEBRATES

Data on concentrations of selenium in invertebrates at KR show levels 12 to 130 times as contaminated as those collected at Volta Wildlife Area during the same period (Table 2-7). More recent data on selenium concentrations in invertebrates from KR and vicinity are available in a recent Lawrence Berkeley Laboratory report (LBL 1986). These data are used in the Exposure Assessment section of this report.

BIRDS

Ohlendorf, et al. (in press) found reproductive problems in aquatic birds nesting at KR in 1983-1985. Samples of bird eggs and livers collected at KR contained elevated levels of selenium. According to Ohlendorf (pers. comm.), selenium concentrations in livers of American coots collected in 1984 from KR contained almost twice the mean concentrations of selenium found in livers of coots collected at KR in 1983 (81.5 and 43.1 mg/kg, dry weight, respectively). Selenium concentrations in livers of ducks collected at KR in 1983 averaged 19.9 mg/kg dry weight (Presser and Ohlendorf in prep.). In areas without selenium contamination, dry

Table 2-7
SELENIUM CONCENTRATION (PPM DRY WEIGHT) IN COMPOSITE SAMPLES OF INVERTEBRATES, MAY 1983

	Volta Wildlife Area			Kesterson Reservoir		
Sample	N[a]	Mean[b]	(Range)	N	Mean	(Range)
Water boatmen (Corixidae)	5/5	1.91	(1.1-2.5)	2/2	22.1	(20-24)
Midge larvae (Chironomidae)	3/3	2.09	(1.5-3.0)	3/3	139	(71-200)
Dragonfly nymphs (Anisoptera)	2/2	1.29	(1.2-1.4)	6/6	122	(66-179)
Damselfly nymphs (Zygoptera)	2/2	1.45	(1.2-1.7)	3/3	175	(119-218)

[a]Number with measurable concentrations/number analyzed.

[b]Geometric means, computed only when selenium was measurable in at least 50 percent of samples.

Source: Modified from Ohlendorf et al. (in press a).

weight concentrations are usually less than 1 mg/kg in eggs, and less than 10 mg/kg in livers of freshwater birds (Ohlendorf pers. comm.).

Data available on the rates of embryonic mortality and deformity during the 1985 breeding season at KR (Table 2-8) indicated that of 124 nests monitored, 39.5 percent contained at least one dead or deformed embryo (Ohlendorf pers. comm.). The 1985 data indicated that nesting failures and high rates of embryotoxicity continued to occur, despite an active hazing program in 1985. In contrast, researchers found no abnormalities in embryos from nests monitored through late stages of incubation or hatching at Volta Wildlife Area in 1983-1985. Nests studied included those of pied-billed grebes (Podilymbus podiceps), killdeer (Charadrius vociferus), mallards (Anas platyrhynchos), northern pintails (A. acuta), gadwalls (A. strepera), cinnamon teal (A. cyanoptera), American coots (Fulica americana), black-necked stilts (Himaatopus mexicanus), American avocets (Recurvirostra americana), and eared grebes (Podiceps nigricollis).

The expected incidence of major external malformations in hatchlings of uncontaminated wild populations of birds and in embryos of laboratory-incubated mallard eggs is less than one percent (Pomeroy 1962, Gilbertson, et al. 1976, Hoffman 1978, Hill and Hoffman 1984).

Studies by Heinz, et al. (in press) indicated that when mallards were fed diets containing 10 mg/kg selenium as selenomethionine, some embryos had deformities similar to those observed at KR. Selenium concentrations in eggs of aquatic birds at KR were far higher than those at the Volta Wildlife Area which served as a control.

In 1983, only a few young were observed from the presumed 258 coot eggs hatched at Kesterson NWR, and only one young eared grebe was observed of the presumed 211 eggs hatched (Ohlendorf et al. 1986). The number of young coots surviving to adulthood is unknown. Despite thorough searches, no coot broods were observed, although coot and grebe broods were observed at Volta Wildlife Area. No coots nested at KR in 1984 or 1985 (Ohlendorf pers. comm.).

In 1984, no American avocet or black-necked stilt broods were observed past 2.5 weeks of age at KR (Niesen and Williams 1985). In 1985, no American avocet hatchlings over 3 weeks of age were observed at KR. Avocet and stilt hatchlings up to 6 weeks of age were observed at Volta Wildlife Area. No survival of juvenile avocets or stilts was recorded at KR, while recruitment of juvenile avocets and stilts into the adult populations appeared normal at Volta Wildlife Area in 1984 and 1985. In addition, more hatchling carcasses were found at KR in 1985 than in 1984 (Niesen and Williams 1985).

Table 2-8
SUMMARY OF FREQUENCIES OF MORTALITY AND DEFORMITIES IN EMBRYOS AND CHICKS OF AQUATIC BIRDS NESTING AT KESTERSON RESERVOIR, 1983-85

Species/ Year	Nests[a]	Nests with Embryotoxicity[b]					
		Dead		Deformed		Total	
		No.	Percent	No.	Percent	No.	Percent
Coot							
1983	59/91	35	(59.3)	25	(42.4)	38	(64.4)
Eared grebe							
1983	141/163	84	(59.6)	22	(15.6)	89	(63.1)
Stilt							
1983	101/125	17	(16.8)	18	(17.8)	24	(23.8)
1984	63/189	7	(11.1)	12	(19.0)	14	(22.2)
1985	69/96	20	(29.0)	23	(33.3)	30	(43.5)
Avocet							
1983	16/16	0	(0)	0	(0)	0	(0)
1984	19/51	0	(0)	0	(0)	0	(0)
1985	22/35	4	(18.2)	4	(18.2)	5	(22.7)
Killdeer							
1984	12/32	0	(0)	0	(0)	0	(0)
1985	16/25	7	(43.8)	3	(18.8)	8	(50.0)
Ducks							
1983	30/42	5	(16.7)	3	(10.0)	7	(23.3)
1984	13/36	6	(46.2)	0	(0)	6	(46.2)
1985	17/27	6	(35.3)	2	(11.8)	6	(35.3)

[a]Monitored/found; nests monitored to hatching or from which a late-stage embryo was collected/nests found during study, including those lost to predation, flooding, desertion, etc.

[b]Dead = number of nests (and percent) with one or more dead embryos; deformed = nests with one or more deformed embryos or chicks; total = sum of all nests with at least one dead or deformed embryo or chick. All percentages calculated by dividing by number of "monitored" nests.

Source: Ohlendorf (pers. comm. b).

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Selenium concentrations in duck muscle tissue from 1984 collections at Kesterson NWR by the California Department of Fish and Game ranged from 0.2-9.2 mg/kg wet weight (Daniel pers. comm.). Because of potential risks to human health from consuming foods with high selenium concentrations, Department of Health Services recommended that no waterfowl from Kesterson NWR be consumed (Kizer pers. comm.). Also, the USFWS has prohibited hunting and fishing at KR since 1984.

MAMMALS

A study of potential selenium contamination of mammals at KR was conducted in 1984. Species collected at KR and at Volta Wildlife Area included the California vole (*Microtus californicus*), harvest mouse (*Reithrodontomys megalotis*), house mouse (*Mus musculus*), ornate shrew (*Sorex ornatus*), desert cottontail (*Sylvilagus auduboni*), California ground squirrel (*Citellus beecheyi*), and muskrat (*Ondatra zibethica*). Preliminary results are reported below.

Reproductive problems were noted for California voles and house mice at KR, but not at Volta Wildlife Area. Western harvest mice and ornate shrews showed reproductive activity at KR, but a comparison with a control area could not be made since no females of either species were caught at Volta Wildlife Area (Clark pers. comm.).

Selenium concentrations were higher than background in the livers of specimens from KR for all species except the California ground squirrel (Clark pers. comm.). Preliminary data for the four most abundant species in this sample (California vole, harvest mouse, house mouse, and ornate shrew) are presented in Table 2-9; for these species, selenium levels at KR were 10 to 1,000 times higher than those at the Volta Wildlife Area. Livers from the carnivorous ornate shrews averaged 6 times more selenium than harvest mouse livers and 22 times more than California vole livers. The mean body burden of these species of herbivores (California vole, house mouse, and harvested mouse) shows a selenium level of 8.18 mg/kg. The single sample of ornate shrew, a small carnivorous rodent, had a body burden of 47.9 mg/kg, or about 6 times higher than found in herbivorous rodents of a similar size. Larger rodents, California ground squirrel and muskrat, had generally lower liver tissue selenium than observed in small rodents.

HUMAN POPULATIONS

The Merced County Health Department conducted a limited public health survey of persons living directly adjacent to KR compared to a control group from Gustine. This survey included a questionnaire and blood, urine, and hair analyses. Based on the limited amount of human toxicological information

Table 2-9
SELENIUM CONCENTRATIONS (PPM DRY WEIGHT) IN
LIVERS AND WHOLE BODIES OF ABUNDANT SMALL MAMMAL SPECIES FROM
KESTERSON RESERVOIR AND VOLTA WILDLIFE AREA (PRELIMINARY DATA)

	Volta Wildlife Area				Kesterson Reservoir					
	Liver				Liver				Whole Bodies	
Species	Pond	N	Mean[a]	(Range)	Pond	N	Mean	(Range)	N	Mean (Range)
California vole	5	5	0.228	(ND-1.4)[b]	2	5	119	(61-250)	2	23 (13,33)
	7	5	0.229	(ND-1.2)	5	14	7.79	(ND-38)	2	2.4 (ND, 4.6)
					7	6	4.29	(3.3-5.8)	1	1.4
					9	2	4.85	(4.8-4.9)		
					11	1	9.2			
Harvest mouse	5	1	2.1		5	5	15.3	(6.5-34)	2	3.2 (2.4, 4.0)
	7	4	1.69	(1.2-2.2)	6	4	38.2	(19-73)	1	27
					7	2	15.5	(9.0-22)		
House mouse	5	5	2.67	(1.9-3.7)	2	2	14.5	(11-18)	2	18.1 (82,28)
					5	5	4.17	(ND-41)		
Ornate shrew	This single shrew from Volta Wildlife Area was not analyzed				7	8	92.7	(13-210)	4	47.9 (10-100)
					11	1	100			
Muskrat	6	1	ND		Drain	1	1.7			
	10	1	1.5		3	3	32.1	(18-92)		
	12	1	0.82		11	1	2.5			
	13	3	0.351	(ND-0.96)						
	14	1	1.9							
California Ground Squirrel	4	1	0.58		8	2	1.82	(0.73, 2.9)		
	12	1	0.93		11	1	0.81			
	13	1	1.1							
Cottontail[d] Rabbit	1	1	0.14		9	1	2.1			
	5	1	0.13		10	2	2.2	(1.1, 3.3)		

[a]Means are geometric for samples of N>2 because of skewness in the data. ND values are entered at 0.1 ppm, which is the detection limit.

[b]Selenium not detected.

[c]Entire animal minus stomach contents. Whole bodies not analyzed for Volta.

[d]Thigh muscle only.

Source: Clark (pers. comm.).

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available for selenium, no evidence was found to indicate acute toxic effects on area residents resulting from exposure to KR (Merced County Health Department 1985).

A public health selenium monitoring program for workers at KR was instituted at KR in 1984. From October 1984 to the present, blood chemistry and blood and urine selenium analyses were performed. Symptoms of acute or chronic selenium toxicity were not observed, and serum and urine selenium levels are within normal ranges (USBR 1986b).

IDENTIFICATION OF CONSTITUENTS FOR RISK CHARACTERIZATION

Table 2-10 summarizes the results of the foregoing analyses. Based on this table, only boron and selenium are of potential concern with regards to this Risk Assessment. The following constituents are not of concern because they have not exceeded standards or guidelines in past measurements of SLD drainwater, KR surface water, and KR groundwater: cadmium, copper, manganese, and nickel. The following constituents are not of concern because they have not accumulated in KR soils above background concentration, and their concentrations in KR groundwater supplies do not exceed standards or guidelines: chromium, mercury, molybdenum, and zinc. TDS is not of concern, even though concentrations in KR groundwater supplies exceed standards and guidelines, because no evidence exists that TDS concentrations in applied groundwater will cause adverse wildlife effects in KR.

Boron is an essential nutrient for plants in low concentrations and exhibits toxic affects at higher levels. Reviews of boron nutritional requirements (Gupta, et al. 1985) and toxicity (Maas 1986) have been summarized by USBR (1986a). Typically, plants will exhibit toxic effects when, depending upon their tolerance, the boron concentrations exceed 200 mg/kg. However, many intolerant species of plants are affected by much lower levels of boron (5 to 50 mg/kg). Boron is accumulated in plant tissues at variable rates dependent upon species metabolism, soil, water, transpiration, and other variable environmental factors (Gupta, et al. 1985, Maas 1986, USBR 1986a).

Analytical results from 350 stem and leaf tissue samples of vegetation collected at KR had leaf tissue concentrations ranging from 10 to 610 mg/kg boron, with an average of 174 mg/kg (USBR 1986a). Boron levels exceeded 200 mg/kg in 36 percent of the plant samples, which represented all ponds at KR.

Table 2-10
SUMMARY OF CONTAMINANT LEVELS IN KR MEDIA

Constituents	Drainwater, Surface Water, or Shallow Groundwater > Standards?	KR Soils > Background?	KR Water Supply Groundwater > Standards?	KR Biota > Background?
Boron	Yes	No	Yes	Yes
Cadmium	No	--	--	--
Chromium	Yes	No	No	No
Copper	No	--	--	--
Manganese	No	--	--	--
Mercury	Yes	No	No	No
Molybdenum	Yes	No	No	No
Nickel	No	--	--	--
Selenium	Yes	Yes	No	Yes
Zinc	Yes	No	No	No
TDS	Yes	NA	Yes	NA

Note: NA = Not applicable.

In a 1983 study of trace element concentrations in rooted plant leaf tissues, Ohlendorf, et al. (1986a) compared samples from sites exposed to drainwater at KR to a control site at Volta Wildlife Management Area. The results showed boron in one plant sample from the Volta area contained 34 mg/kg dry weight, while 9 samples taken at KR ranged from 270 to 510 mg/kg (mean = 382 mg/kg) or more than 10 times the level of the control site. Aquatic insect samples taken at KR had a mean of 45.2 mg/kg boron (range 36-54 mg/kg), while samples from Volta contained 13.4 mg/kg (range 6.7-35 mg/kg). Similarly, mosquitofish at KR had a mean tissue boron level of 11.1 mg/kg (range 8.0-20 mg/kg), while Volta samples showed a level of only 2.75 mg/kg (range ND-3.6 mg/kg). The exposure of the KR food chain to high levels of boron in drainwater has resulted in apparently higher levels in the organisms investigated thus far.

The implications of the available data are difficult to interpret given the present state of knowledge for several reasons. First, no data are available that indicate the dietary intake of boron by higher food chain components such as birds or carnivores. Secondly, little information is available that indicates potential toxic effects of boron in wildlife species.

Sax (1984) reports an oral-LD50 for mice of 2,000 mg/kg as boric acid. Limited acute aquatic toxicity data for mosquitofish indicate that relatively high boron concentrations are needed to achieve a lethal dose. Boron concentrations ranging from 3,600 to 5,600 mg/l (sodium borate and boric acid, respectively) have been reported as being toxic (SWRCB 1963). Acute and chronic toxic effects of boron in the diet of wild birds or mammals has not been reported in the literature. Further studies are needed to determine whether ingested boron adversely affects wildlife reproduction (SWRCB 1986). Also, because of the mobility of boron, it is expected that boron presently accumulated in KR vegetation will not remain in the KR ecosystem although it may be reapplied as part of the water under the FRP.

Boron is not evaluated further in this Risk Assessment because, as discussed above, there is no existing evidence linking boron to observed KR wildlife effects; evidence does exist for selenium. Further study of the potential toxic effects of boron on wildlife species does, however, appear warranted. If such studies do link boron to wildlife toxicity, then risks to wildlife would be greater for the FRP than for the Onsite Disposal Plans, since the FRP includes using high boron local groundwater as a KR water supply (see Chapter 3).

Chapter 3
EXPOSURE ASSESSMENT

INTRODUCTION

Risk assessment requires estimating selenium exposure that may occur as a result of implementing each of the several KR cleanup alternatives.

This section presents a description of the cleanup alternatives being considered for KR, a description of the biogeochemistry of selenium, a description of potential major selenium exposure pathways resulting from these cleanup alternatives, an identification of key species which are potential receptors of contamination from these pathways, the population sizes of the key species, a description of exposure pathway components, an estimate of selenium transfer factors (and their uncertainties) between pathway components, and key species diet factors.

CLEANUP ALTERNATIVES

Cleanup alternatives under consideration for implementation at KR were developed and qualitatively evaluated in the Kesterson Program EIS (USBR 1986a). These alternatives are: the Phased Approach, the Onsite Disposal Plan, and the Offsite Disposal Plan. For the purposes of this risk assessment, it is necessary to consider components and subalternatives of these plans.

PHASED APPROACH

The phased approach consists of three components: the Flexible Response Plan (FRP), the Immobilization Plan, and the Onsite Disposal Plan.

Flexible Response Plan

Under the FRP, the southern ponds (Ponds 1-8) where most of the soil selenium contamination occurs would be flooded with low selenium groundwater, and the northern ponds (Ponds 9-12) would not have water applied. Vegetation in the northern ponds would be controlled by discing. Some areas of the northern ponds could be seasonally wet when groundwater rises typically November through April.

Immobilization Plan

The Immobilization Plan is similar to the FRP to the extent that water would continue to be applied to the southern ponds and the northern ponds would not have applied water.

Emergent vegetation in the southern ponds would be harvested and disposed offsite. In the northern ponds, exposure to contamination would be controlled through discing, and if necessary, vegetation harvesting and offsite disposal, or filling seasonal wetlands with soil. These management actions will reduce risk to wildlife compared to the FRP. Contamination exposure in the northern ponds under the Immobilization Plan is expected to be between that resulting from the FRP and the Onsite Disposal Plan. The Immobilization Plan is therefore not considered further in this risk assessment. Because insufficient information currently exists regarding the magnitude of reduced risks to wildlife achievable with this plan, the immobilization plan will be tested as part of the FRP.

Onsite Disposal Plan

Under the Onsite Disposal Plan, contaminated soils and vegetation would be excavated and disposed of onsite in a lined and capped landfill. This plan has two subalternatives: excavating KR soil with selenium levels greater than 4 mg/kg and harvesting all above-ground vegetation (approximately 450,000 cubic yards) (Onsite-1) and excavating all KR soil and vegetation (approximately 1,000,000 cubic yards) (Onsite-2). These alternatives are addressed in this risk assessment.

ONSITE DISPOSAL PLAN

Under this plan, onsite disposal (either 450,000 or 1,000,000 cubic yards) would be implemented immediately rather than as the third component of the phased approach. Since the risk assessment does not consider the time frame of plan implementation, the risks of this plan are essentially identical to the phased approach onsite disposal plan.

OFFSITE DISPOSAL PLAN

This plan is similar to the Onsite Disposal Plan with the exception that excavated and harvested material would be disposed of offsite rather than onsite. Since the risks of landfill failure are not being considered, the risks of this plan are essentially identical to the phased approach onsite disposal plan.

SELENIUM BIOGEOCHEMISTRY

The major features of selenium chemistry that affect its movement and toxicity are associated with changes in its oxidation state and the resulting differences in chemical properties.

Selenate is the most mobile form of selenium and makes up the majority of selenium that has been delivered to KR via the SLD. Selenium was removed from the drainwater applied to KR, apparently by biological processes, and also from the water as it seeped into the groundwater through the anaerobic sediments, probably by both chemical and biological processes. This selenium which has accumulated in the soils and sediments of KR is in reduced inorganic forms, such as selenite and elemental selenium, and in organic selenium compounds. This accumulated selenium can potentially be mobilized into overlying water by physical, chemical, and biological processes and hence again become bioavailable or may be transported through the food chain via the detritus pathway.

EXPOSURE PATHWAYS

Potential exposure pathways to residual selenium contamination at KR include food chain or ingestion of contaminated sediments, water, plants, and animals, direct contact and dermal absorption, and air migration and inhalation. All of these are possible pathways for potentially exposed human populations.

Food chain exposure is considered the most significant exposure pathway for wildlife at KR. No information reviewed suggests that dermal exposure or inhalation is a significant exposure pathway for selenium at KR. Fish, however, are directly affected by selenium in the water column but selenium concentrations in surface water under all plans are expected to be below the EPA criterion to protect aquatic life (see Chapter 4).

The fish and wildlife food chain exposure pathways can be divided into subpathways which relate to the properties and movement of selenium. As described in the Kesterson Program Final EIS (USBR 1986), the potential exists for residual soil selenium contamination to move into terrestrial and aquatic food chains. The terrestrial food chain represents the dry areas of KR after implementation of a cleanup alternative (e.g., dry areas of northern ponds under FRP). The aquatic food chain represents either the permanently wet areas (e.g., the southern pond under FRP) or the seasonably wet areas (e.g., the low areas of the northern ponds under the FRP and the low areas of all the ponds under the Onsite Disposal Plan). The aquatic food chain is further divided into a benthic pathway, a water column pathway, and a rooted plant pathway.

EXPOSED POPULATIONS

HUMAN POPULATIONS

Insufficient information exists to perform a quantitative risk assessment for potentially exposed human populations at KR. The Kesterson Program Final EIS (USBR 1986a) presents a thorough, comprehensive analysis of exposure of human populations to KR contaminants, based on the most recent data available. Potentially exposed populations are described below.

Foragers

There is a lack of data on the potentially exposed population, such as estimates of the population size, frequency of their use of the area, their dietary habits in general, what items at KR they may consume, their normal dietary intake of selenium, the selenium concentrations of some potential food items, or the amount of food or other contaminated media they may take in. A preliminary ethnographic survey has been recently completed (USBR, 1986c), but further information would be necessary to allow quantitative risk assessment.

Adjacent Residents

Groundwater exposure is expected to be minimal due to limited selenium migration in the groundwater (USBR 1986a, LBL 1986) and lack of groundwater beneficial use as described in the Kesterson Program Final EIS (USBR 1986a).

Workers

Each alternative has a different exposed population. They include the normal Kesterson workers and researchers, but excavation would also include construction workers.

Hunters

Hunting is not allowed at KR. There is no information available on the fraction of total diet that comes from KR of the birds shot at adjacent duck clubs or other offsite areas.

WILDLIFE POPULATIONS

A list of species present at KR is given in Appendix A and is based on USBR (1986a). The species at KR represent a variety of trophic levels and, hence, selenium exposure potential. Criteria for selection of species for risk characterization are described below.

IDENTIFICATION OF KEY FISH AND WILDLIFE SPECIES

Appendix A presents a list of wildlife species known or suspected to use KR. It was not possible to perform a quantitative risk assessment for each of these species due to time and budget constraints. However, it is not necessary to perform a risk assessment for each of these species because indicator species can be selected to represent the range of possible exposure pathways and risks. Therefore, a quantitative risk assessment performed for these indicator species will depict risks to the wildlife species using KR.

Selection of indicator or key fish and wildlife species is based on several considerations: they are the terminus of a major KR food chain exposure pathway; impacts of KR on the species have been observed in the past; they are rare or endangered species; they have particularly sensitive life stages; or information is available on the effects of selenium exposure for the species. Not all of the species selected, of course, satisfy all of these criteria. Descriptions of the selected species and rationales for their selection follow.

Mallard

The adult mallard is an omnivore with highly variable feeding habits. During nesting and egg-laying, the diet of the adult female changes from one relying primarily on vegetation to one that includes more protein. Exposure during this period was estimated because of the potential impact on reproduction. The mallard duckling is probably very sensitive to selenium toxicity and its diet consists primarily of aquatic invertebrates. Thus, the exposure of the mallard duckling is probably similar to that of the tricolored blackbird (discussed below).

The mallard is an important game species in the Pacific flyway. Another consideration in the selection of mallards is the fact that there is a relatively large amount of selenium and other toxicology data available for them.

American Coot

The adult American coot is an aquatic species with little dependence on the benthic community at KR. Feeding habits of the adult coot do not vary substantially with respect to sex. The adult coot feeds primarily on terrestrial and aquatic plants, insects, and other epiphytal fauna.

Black-necked Stilt

The adult black-necked stilt relies heavily on the littoral benthic epifauna. Stilts are wading birds that tend to eat

epifauna that they can see. Among the four species, stilts rely on the benthic community to the greatest extent.

Tricolored Blackbird

The young tricolored blackbird (*Agelaius tricolor*) (through fledgling) is fed almost exclusively adult insects and aquatic insect larvae. The fledgling blackbirds and stilts tend to rely on similar trophic levels for food, although the blackbird diet is not generally comprised of a significant amount of epibenthic species. The status of the tricolored blackbird as a federal candidate for threatened and endangered species listing was also a factor in its selection.

Eared Grebe

The eared grebe is a fish-eating bird in which KR impacts have been observed in the past (Ohlendorf, et al. 1986a). Although the eared grebe does not exclusively eat fish, it was selected as a key species because fish are an important part of its diet and eared grebes also have limited feeding range, therefore, tending to have a restricted offsite exposure.

Mosquitofish

The mosquitofish (*Gambusia itffinus*) is the only fish which currently exists at KR; it is highly resistant to selenium toxicosis. Mosquitofish were introduced into California in 1922 and have since spread to waters throughout the state. The species has a worldwide distribution in warm waters due to its use for mosquito-control purposes. Mosquitofish are omnivorous and opportunistic feeders utilizing whatever organisms are most abundant near the waters surface. The diet may consist of algae, zooplankton, fishes, terrestrial insects and aquatic invertebrates (Moyle 1976). Under crowded conditions or periods when animal food is scarce, they may feed extensively on filamentous algae and diatoms (Moyle 1976). Mosquitofish were selected because they can survive with high tissue selenium levels and thus may represent a concentrated source of selenium.

San Joaquin Valley Kit Fox

The kit fox was included as the terrestrial food chain receptor because it is a federal and state-listed endangered species. USFWS surveys indicate that kit foxes forage at KR as there have been approximately 25 confirmed observations of this species in the vicinity of KR since 1984. The frequency of sitings has apparently increased in the last several years. The kit fox diet consists of both large grassland animals such as rabbits, hares, California ground squirrels and small mammals, including California voles,

deer, mice and other small rodents. Incidental food items include birds, reptiles, and insects. Little data exist regarding the specific diet of the kit fox in the KR area and the ratio of quantity of food obtained in the vicinity of KR to the total prey consumption of a typical kit fox is unknown. Furthermore, the size of the kit fox population near KR is not well known. USBR has funded a kit fox study to address these issues.

ESTIMATES OF KEY SPECIES POPULATION SIZES

The estimates of population densities and estimates of past KR-related mortalities given in Table 3-1 are based on data from published literature, unpublished surveys by the USFWS and California Department of Fish and Game (DFG), consultation with personnel from these agencies, and other local experts. These data are provided to put in perspective the relative risks of selenium exposure of each population. They are not intended to indicate effects of past exposure to selenium at KR. The population data are indices of density and in most cases the actual values are unknown. They are presented here only for the purposes of assessing the relative risks of fish and wildlife contamination under the cleanup alternatives being considered at KR. Losses given for KR include all sources of mortality that have been directly observed, including predation, disease, and chemical-induced toxicosis. The numbers do not reflect reproductive failures that migrant birds may experience on their breeding grounds that could be due to contaminants acquired at KR.

As Table 3-1 suggests, the risks of contamination-induced mortality vary greatly between these species. The data for mallards suggest that this species is at low risk due to its small population at KR (probably due to the hazing program) relative to its San Joaquin Valley and statewide populations. Both the American coot and black-necked stilt suffered significant mortalities at KR during the period 1983-85, but small numbers of birds (4 percent) were "lost" relative to their San Joaquin Valley and statewide populations. In contrast, the tricolored blackbird population at KR suffered an almost total nesting failure in 1986. Only about 100 fledglings were observed from a colony of approximately 47,000 breeding adults. This total represents more than half the San Joaquin Valley population and more than one-third of the statewide population. The tricolored blackbird is largely endemic to California, so the statewide population approximates the global population for this species (DeHaven pers. comm.). Preliminary USFWS data suggest the cause of this mortality of tricolored blackbird nestlings was due to acute

Table 3-1
KESTERSON BIRD POPULATIONS AND MORTALITIES

	Mallard	American Coot	Black-Necked Stilt	Tricolored Blackbird	Eared Crebe	San Joaquin Kit Fox
Kesterson Reservoir Mortality	1 found dead in 1986[a] 17-22 ducks "lost"[e]	438 "lost" in 1983[e]	197 "lost" in 1985[e]	82,150 "lost" eggs and chicks in 1986[h]	411 "lost" in 1983[e]	No data
Kesterson Reservoir Population	45-100 per day[b]	9,489[f]	50-60 individual nesting in 1986[a]	47,000[b]	17[n]	15-20[m]
San Joaquin Valley Population	89,142[c]	216,623[c]	No data	85,850[i]	No data	5,294[k]
California Population	435,421[c]	427,415[c]	~100,000[g]	133,000[i]	730,250[l]	10,000-14,800[j]
Pacific Flyway Population	1,759,800[d]	562,400[d]	No data	No data[i]	No data	Same as statewide population

[a]Personal communication from Mary Coakley, wildlife hazer, 10-2-86. This value does not reflect nestling mortalities.

[b]Unpublished USFWS hazing data from Kesterson Reservoir - March 1986.

[c]Unpublished USFWS data, 1973-77 average from Pacific Flyway mid-winter waterfowl survey--1986.

[d]Unpublished USFWS data, 1955-85 average from Pacific Flyway mid-winter waterfowl survey.

[e]Unpublished memo from Dr. Harry Ohlendorf to Mr. Ken Anderson of the General Accounting Office, 5/16/86. Includes dead or deformed embryos or chicks and those presumed to have hatched but that failed to survive. Some losses were due to predation, but these cannot be accurately separated from possible mortality due to selenium toxicosis.

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Table 3-1
(Continued)

[f] Maximum average daily use total from unpublished USFWS data 1984-86--see Draft EIS.

[g] "Ballpark" estimate by Ron Jurek, DFG, 10-2-86.

[h] Rough calculation assuming about 23,500 nesting pairs, a clutch size of 3.5, and mortalities of all but 100 fledglings.

[i] Population estimates by Rich DeHaven (USFWS) for the period 1969-1972. Note that this species is largely endemic to California--so the statewide population approximately equals global population.

[j] Range of adult population estimates for California by Morrell (1975).

[k] Based on adult population estimates by Morrell (1975) for Kern, Tulare, Kings, Fresno, San Benito, Merced, Stanislaus, and San Joaquin Counties.

[l] Maximum extrapolated population estimate from Mono Lake, August 30, 1976 (Winkler et al. 1977); actual statewide population is probably much higher than this (Gould personal communication).

[m] Paveglio (personal communication b.). Total adult population in adjacent 25,000-acre range. Up to 5 individuals (including pups) have been simultaneously at Kesterson Reservoir.

[n] Paveglio (personal communication b.). Average daily use for 1982, 1984, and 1985. Peak use is 125-175 during migration.

selenium toxicosis from eating contaminated insects (Paveglio pers. comm. a).

ESTIMATES OF TROPHIC RELATIONSHIPS

Trophic relationships of the key species are summarized in Figures 3-1 through 3-6. These are based on discussions with ecologists familiar with KR and on studies of the ecology of the key species conducted elsewhere (Martin, et al. 1951, Pough 1951, Johnsgard 1975).

ADAPTATION FOR RISK ASSESSMENT

Evaluation of the risk of KR cleanup alternatives to fish and wildlife requires, for each cleanup alternative, a prediction of the exposure of wildlife to selenium. The transfer of selenium through the food chain and concentrations of selenium in food groups were estimated for each cleanup alternative using empirical relationships (transfer factors) derived from studies conducted at KR and elsewhere. The empirical transfer factors served as the basis for the mathematical model used to predict the relationship between selenium in each trophic level and, ultimately, the exposure of key species to selenium. The model is described in Chapter 5.

In order to model and predict selenium transfer and dietary exposure to the selenium transfer pathways shown in Figures 3-1 through 3-6 were simplified. Schematic representations of selenium transfer and exposure used for prediction purposes are shown in Figure 3-7 through 3-9. The simplified selenium transfer diagram was developed in consultation with USFWS personnel after the complex pathways were identified for each of the key species.

The simplified pathways contain all of the basic selenium transfer pathways present in the complex transfer diagrams (Figures 3-1 through 3-6). Although uptake pathways exist that are not depicted in the simplified transfer diagrams (e.g. direct uptake of dissolved selenium by herbivores and carnivores), transfer factors are derived to predict the change in concentrations between compartments or trophic levels that occurs as a result of all uptake pathways. In other words, the concentrations of selenium in a particular compartment is expressed solely as function of the concentrations in the adjacent compartment.

The simplified selenium transfer diagrams contain all of the basic selenium compartments present in the complex pathways. Since data from KR show that many groups contain similar levels of selenium, it is not necessary to distinguish between them for modeling purposes. For instance, there is a

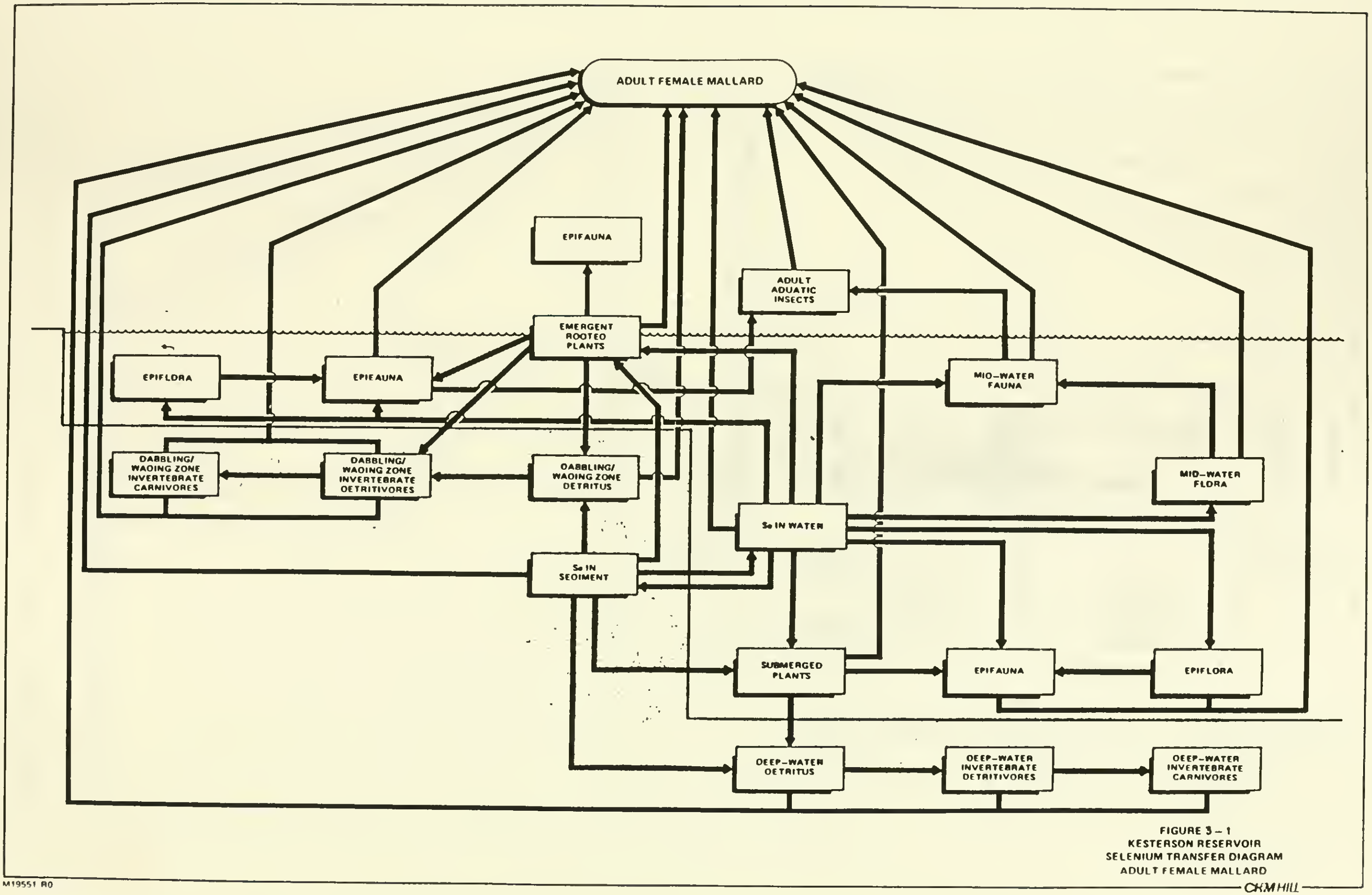

FIGURE 3-1
KESTERSON RESERVOIR
SELENIUM TRANSFER DIAGRAM
ADULT FEMALE MALLARD

M19551 R0 CH2M HILL

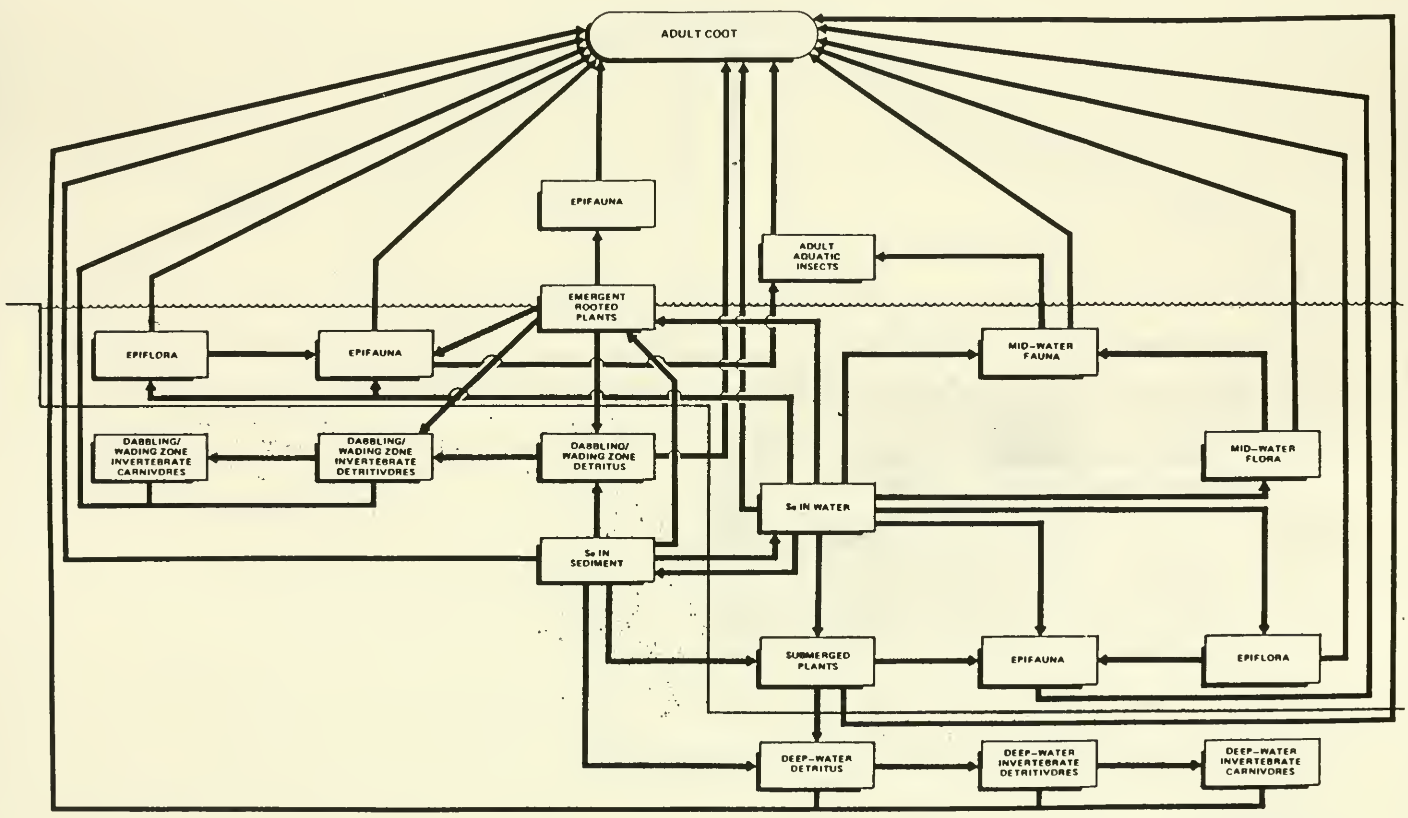

FIGURE 3 – 2
KESTERSON RESERVOIR
SELENIUM TRANSFER DIAGRAM
ADULT COOT

CH2M HILL

M19551.R0

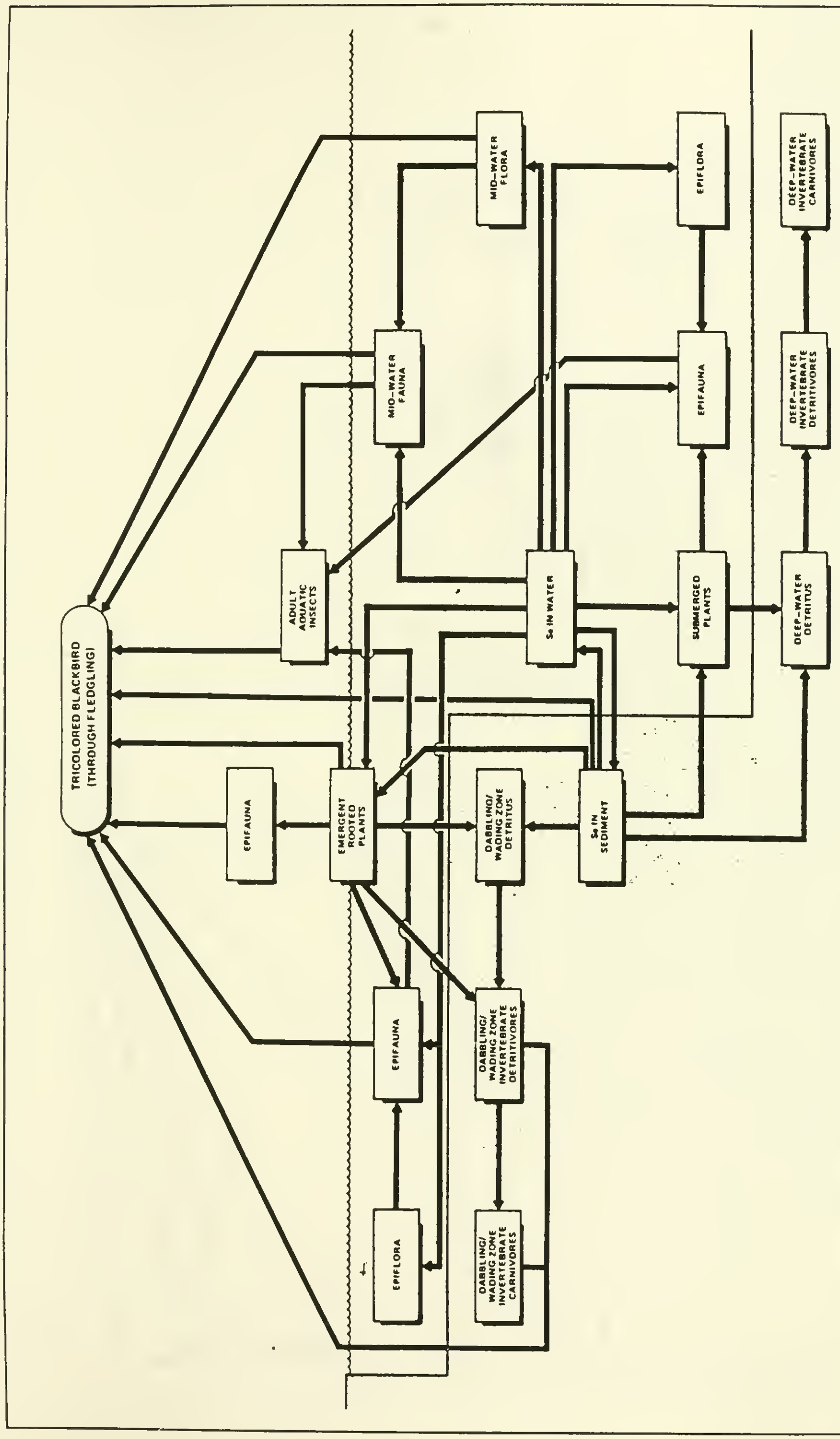

FIGURE 3–3
KESTERSON RESERVOIR
SELENIUM TRANSFER DIAGRAM
TRICOLORED BLACKBIRD
(THROUGH FLEDGLING)

CH2M HILL

M19551 R0

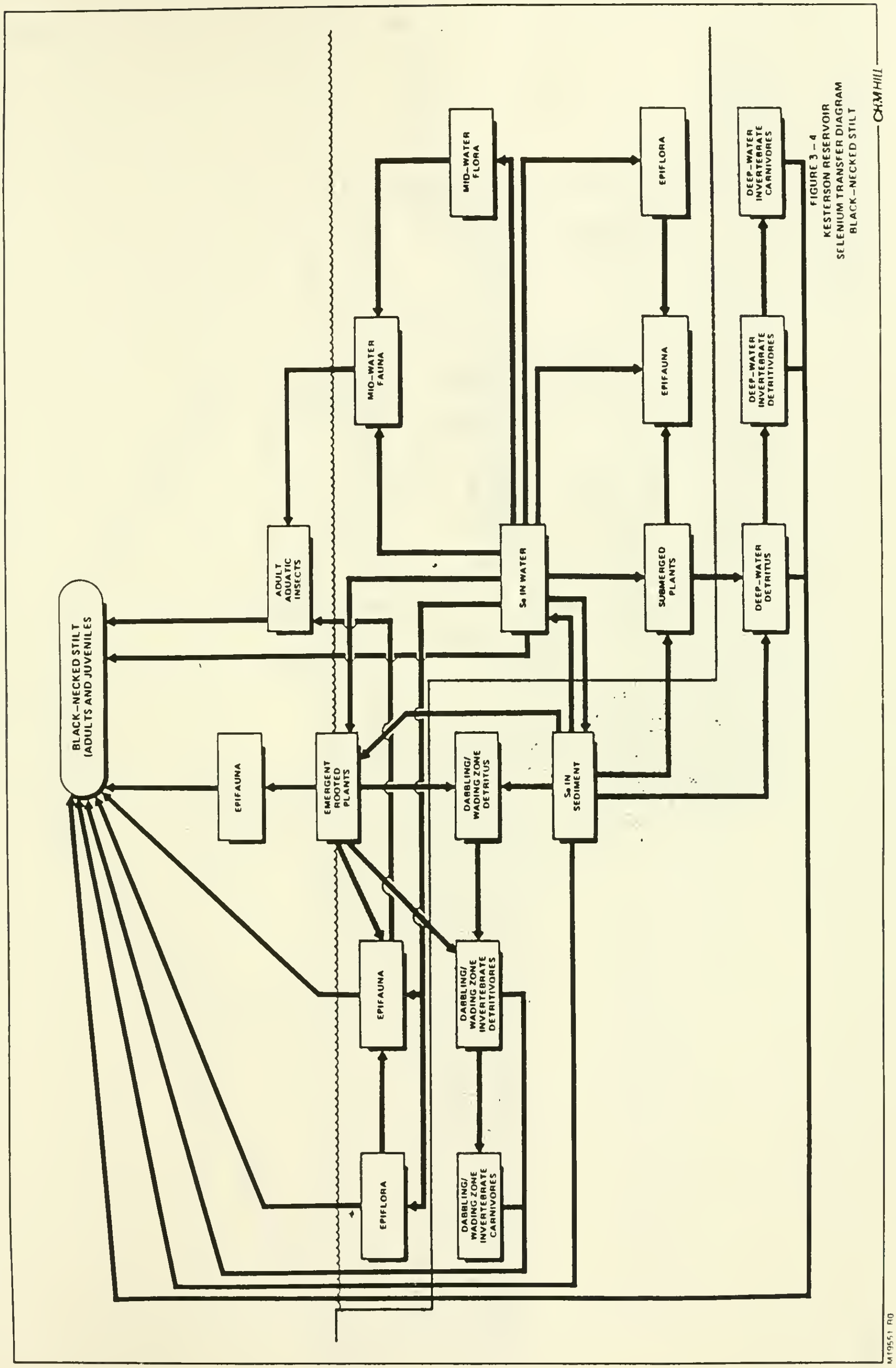

FIGURE 3-4
KESTERSON RESERVOIR
SELENIUM TRANSFER DIAGRAM
BLACK-NECKED STILT

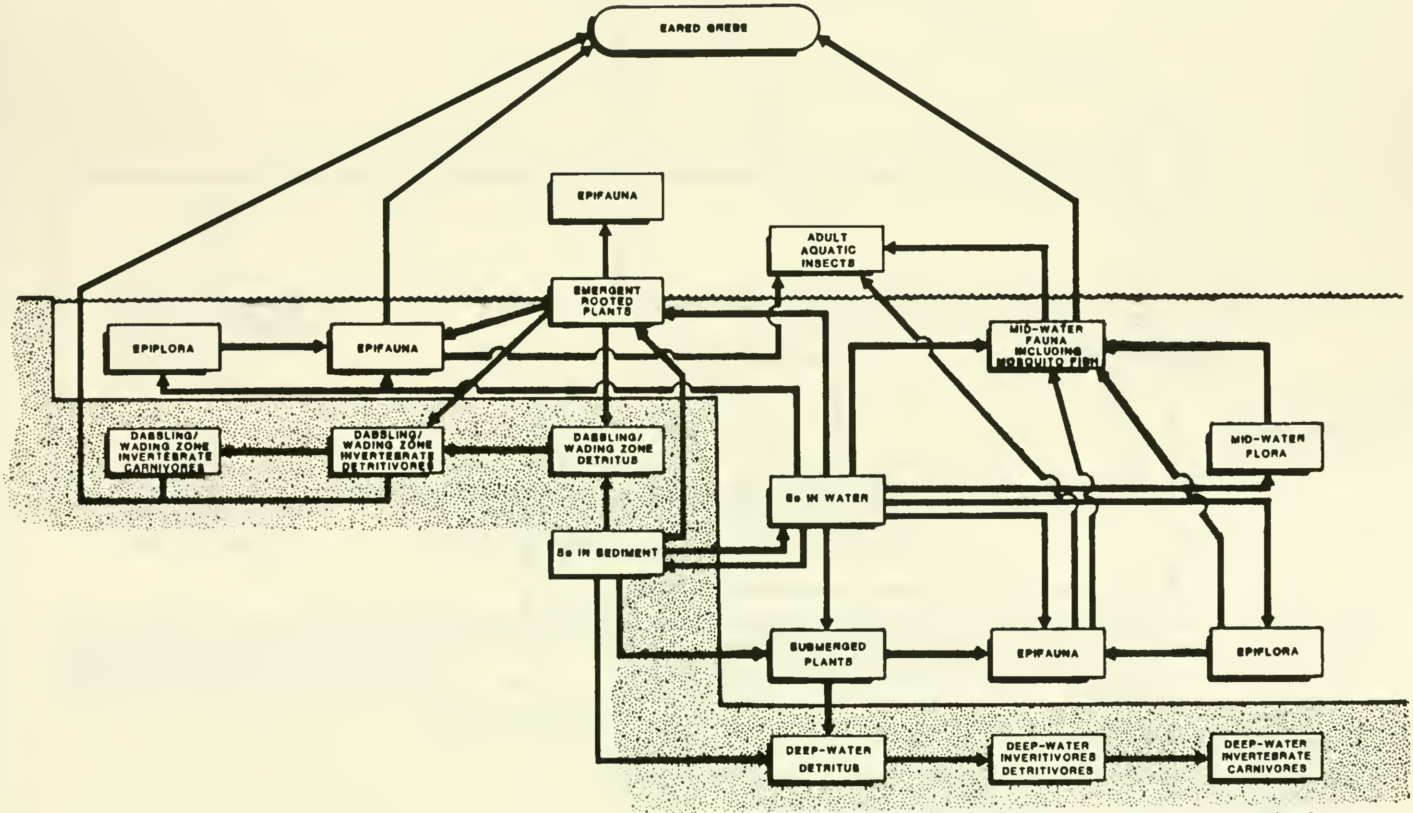

FIGURE 3-6
KESTERSON RESERVOIR
SELENIUM TRANSFER DIAGRAM
MOSQUITOFISH AND EARED GREBE

CH2M HILL

M19551.90

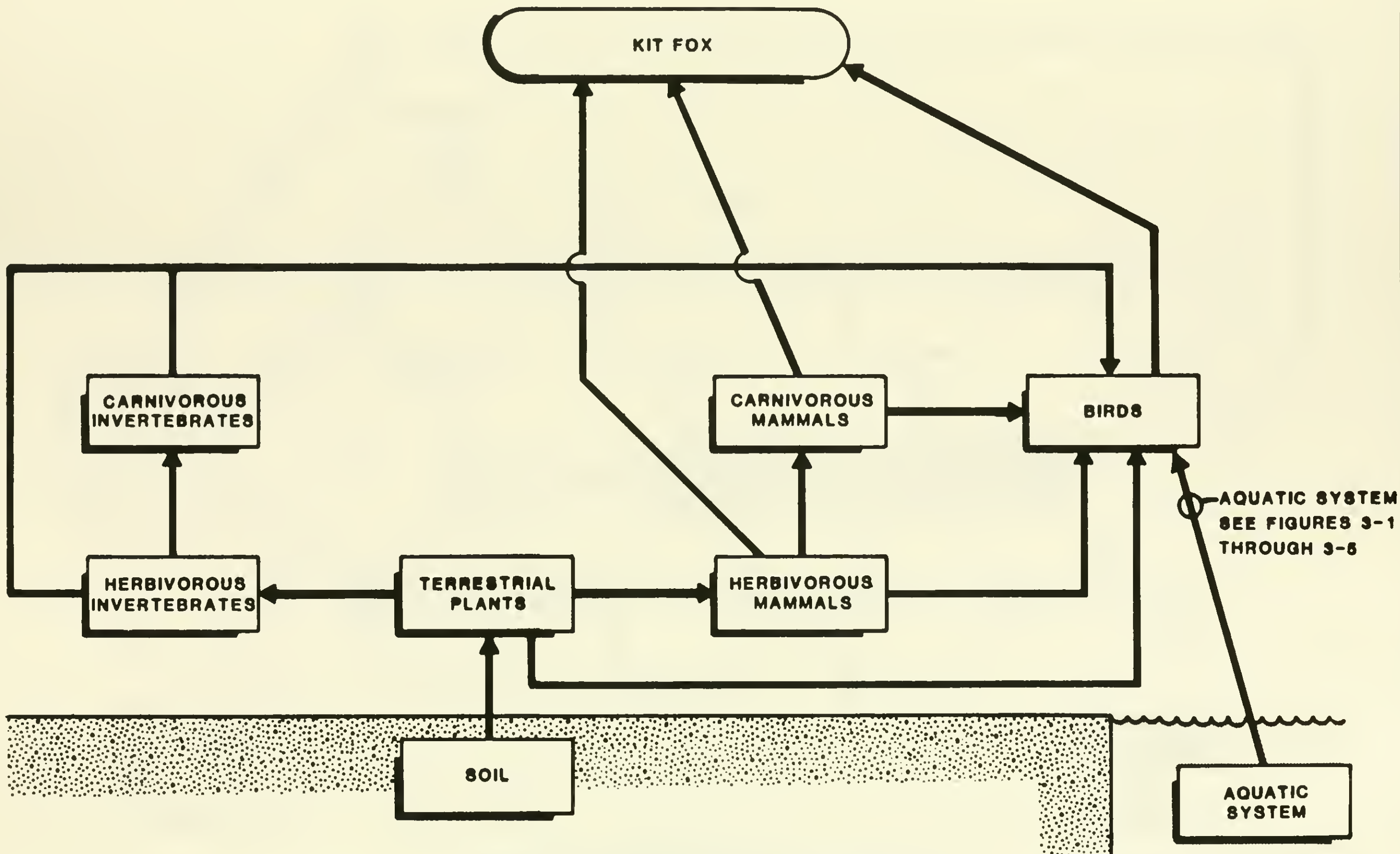

FIGURE 3-6
KESTERSON RESERVOIR
SELENIUM TRANSFER DIAGRAM
KIT FOX

CH2M HILL

M19551.S0

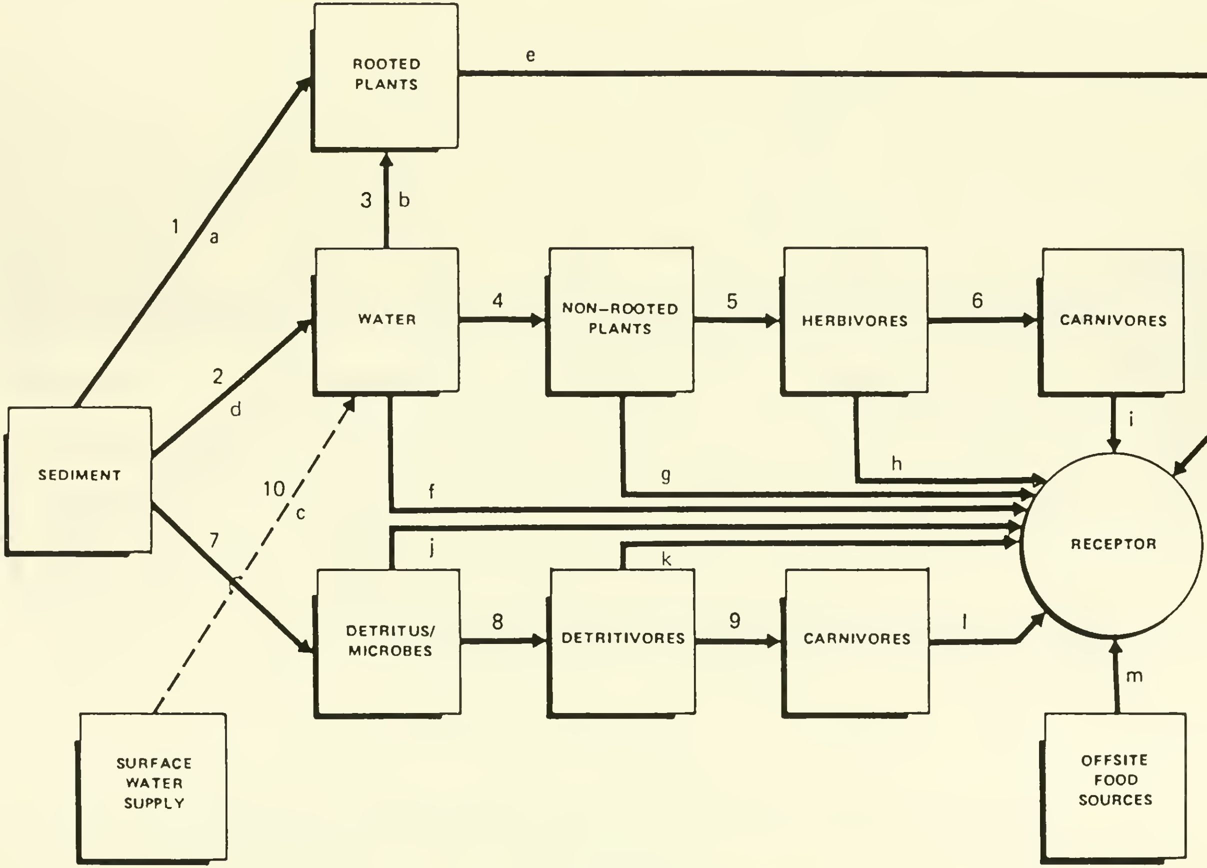

FIGURE 3 – 7
SIMPLIFIED SELENIUM TRANSFER DIAGRAM
WITH KEY TO TRANSFER AND DIET FACTORS

M19551 R0

CH2M HILL

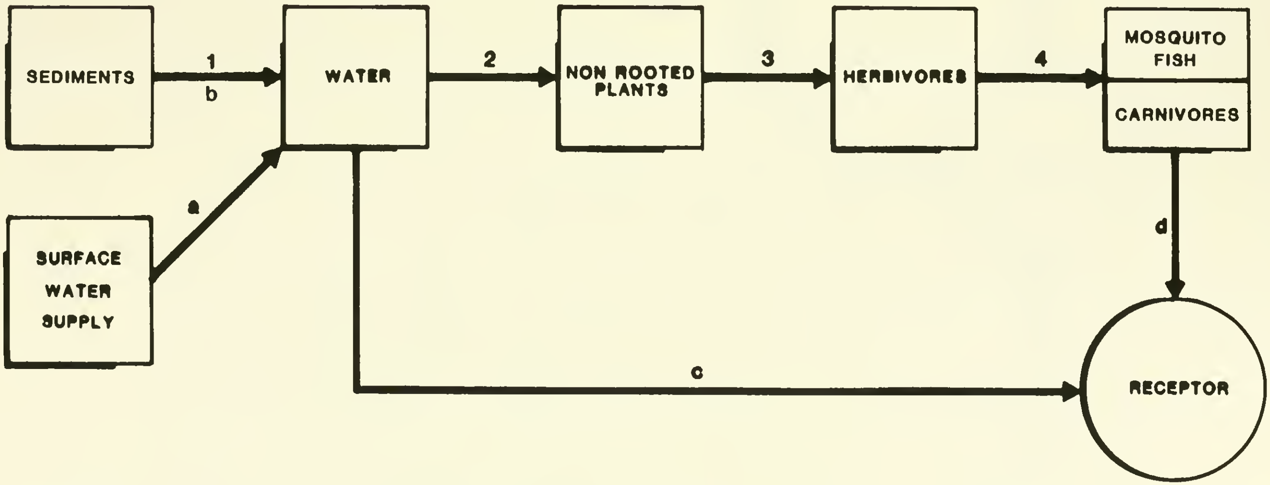

FIGURE 3-8
SIMPLIFIED SELENIUM TRANSFORM DIAGRAM
WITH KEY TO TRANSFER AND DIET FACTORS
MOSQUITO FISH/EARED GREBE

M19551.SO

CH2M HILL

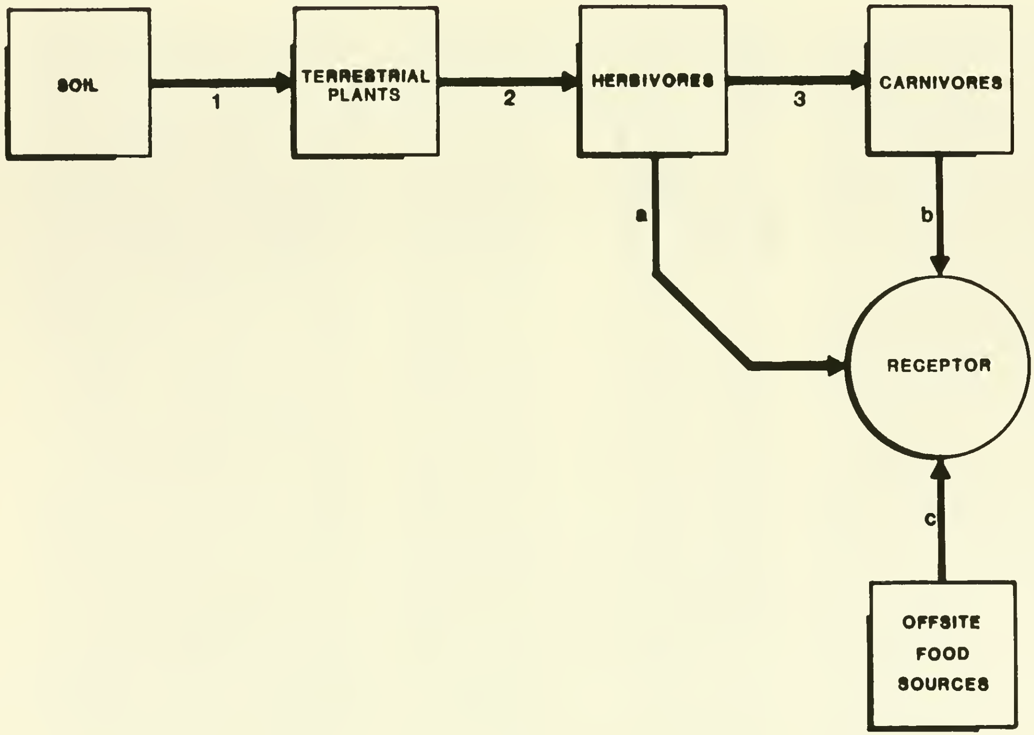

FIGURE 3-9
SIMPLIFIED SELENIUM TRANSFER DIAGRAM
WITH KEY TO TRANSFER AND DIET FACTORS
KIT FOX

CH2M HILL

M19551.S0

variety of non-rooted aquatic plants present at KR, including Nitella, attached diatoms, attached green algae, etc. However, since rooted plants can acquire selenium from sediment and water (and selenium levels in each will be affected differently by each cleanup alternative), selenium levels in rooted plants are expected to respond differently than non-rooted plants to implementation of each alternative.

Associated with the simplified selenium transfer diagram for each of the key organisms are estimates of the selenium concentrations in each compartment (e.g., sediment, water, non-rooted plants, etc.), transfer factors, and diet factors. Associated with each mean estimate is a variance estimate (plus or minus one standard deviation) that reflects empirical variability and confidence in empirical and literature values.

Important aspects of the simplified pathways, including explanations of how key values were determined, are discussed below. Data used to derive transfer factors and their sources are summarized in Table 3-2. The transfer factors are given in Tables 3-3 through 3-5. Other important aspects of applicability of the simplified selenium transfer diagrams to risk assessment are discussed in Chapter 5.

SEDIMENT

Since water applied to KR will have very low selenium concentration (less than 1 μg/l), the major potential source of selenium for biological uptake is the soil. Selenium can enter the biosphere directly from selenium forms in the sediments or it can dissolve in water that will be present in the ponds as described in each alternative.

The amount of selenium currently present in sediments is quite variable but tends to be greater in southern ponds than in northern ponds. In the FRP alternative, where no removal of sediment is involved, a value of 7 mg/kg ±7 (±1 standard deviation) is used. This concentration is representative of the southern ponds which have relatively high sediment selenium concentrations (see Table 4-2, USBR 1986a). The variance component of this estimate reflects the spatial heterogeneity of selenium measured at KR. After excavating sediment with selenium concentrations greater than 4 mg/kg (Onsite Disposal Plan-1), average sediment selenium concentrations will be 3 mg/kg ±2. The Onsite Disposal Plan-2 will result in a sediment selenium concentration of 1.5 mg/kg ±1.

Table 3-2
SUMMARY OF DATA USED TO DERIVE TRANSFER FACTORS[a]
(±1 STANDARD DEVIATION)

	Non-Piscivorous Bird Pathway					
	Past		Flexible Response		Onsite Disposal	
	Value	Source	Value	Source	Value	Source
Sediment	7±7	1	7±7	1	3±2, 1.5±1[b]	1[c]
Rooted Plants	26±18	1	26±18	1	26±18	1
Water	300	1	2-15	2	2-15	2
Non-Rooted Plants	56±5.5	2	0.3-20[c]	4	0.3-20[c]	4
Non-Benthic Herbivores	127±23	2,3	[e]	4	[e]	4
Non-Benthic Carnivores	92±19	2,3	2-270[d]	4	2-270[d]	4
Detritus	26±18	5	26±18	5	26±18	5
Detritivores	56±5.5	2,3	56±5.5	2,3	56±5.5	2,3
Benthic Carnivores	127±23	2,3	127±23	2,3	127±23	2,3
	Fish/Piscivorous Bird Pathway					
Sediment	7±7	1	7±7	1	3±2, 1.5±1[b]	1[c]
Water	300	1	2-15	2	2-15	2
Non-Rooted Plants	56±5.5	2	0.3-20[d]	4	0.3-20[d]	4
Non-Benthic Herbivores	127±23	2,3	[e]	4	[e]	4
Mosquitofish/Carnivores	104±25	2	2-270[d]	4	2-270[d]	4
	Terrestrial Pathway					
Soil	3±2	1	3±2	1	3±2, 1.5±1[b]	1[c]
Terrestrial Plants	30±10	1	30±10	1	30±10	1
Herbivores	10±24	6	10±24	6	10±24	6
Carnivores	48±17	6	48±17	6	48±17	6

Data Sources:

1 USBR 1986a. Standard QA/QC procedures, all data sources given in EIS.
2 LBL 1986. LBL is developing QA/QC procedures, and therefore, data are not final.
3 Ohlendorf et al. 1986. QA/QC procedures specified.
4 Lemly 1985. QA/QC procedures not specified.
5 No specific reference. Assumed majority of detritus comprised of rooted macrophytes.
6 Clark, personal communication.

Note: All standard deviations estimated by dividing range by 6 except those from LBL (1986) which were given in reference. This is based on the assumptions of a normal distribution and that >99% of values are within ±3 stand. dev.

[a] All units mg/kg (d.w.) except water which is µg/l.

[b] Two values given for Onsite Disposal No. 1 and 2, respectively.

[c] Mean value from USBR (1986a)

[d] Range only was given in reference.

[e] Inferred from reference data.

Table 3-3
TRANSFER AND DIET FACTORS FOR SIMPLIFIED SELENIUM TRANSFER DIAGRAM FOR MALLARD, AMERICAN COOT, TRICOLORED BLACKBIRD, AND BLACK-NECKED STILT
(Standard Deviations are in parentheses)

	Past Condition	Flexible Response	Onsite Disposal 1[a]	Onsite Disposal 2
Sediment Conc. (mg/kg d.w.)	7 (7)	7 (7)[b]	3(2)	1.5 (1)
Surface Water Supply (mg/l)	0.3	0	0	0
Transfer Factors				
1 Sediment - Rooted Plants	2.8 (3)	2.8 (3)	2.8 (3)	2.8 (3)
2 Sediment - Water[c]	0.0003-0.002	0.0003-0.002	0.0003-0.002	0.0003-0.002
3 Water - Rooted Plants	81 (21)	81 (21)	81 (21)	81 (21)
4 Water - Non-rooted Plants	187 (22)	500 (50)	500 (50)	500 (50)
5 Non-rooted Plants - Herbivores	2.2 (0.8)	4.0 (2.0)	4.0 (2.0)	4.0 (2.0)
6 Herbivores - Carnivores	0.7 (0.3)	1.5 (0.5)	1.5 (0.5)	1.5 (0.5)
7 Sediment - Detritus/ Microbes	2.4 (2.9)	2.4 (2.9)	2.4 (2.9)	2.4 (2.9)
8 Detritus/Microbes - Detritivores	2.2 (0.8)	2.2 (0.8)	2.2 (0.8)	2.2 (0.8)
9 Detritivores - Carnivores	0.7 (0.3)	0.7 (0.3)	0.7 (0.3)	0.7 (0.3)
Relative Supply Factors[d]				
a Sediment - Rooted Plants	25	25	25	25
b Water - Rooted Plants	75	75	75	75
c Surface Water Supply - Water	100	0	0	0
d Sediment - Water	0	100	100	100

DIET FACTORS[e] FOR
PAST CONDITION, FLEXIBLE RESPONSE, AND ONSITE DISPOSAL

	Adult Female Mallard Nesting	Adult American Coot	Tricolored Blackbird Nestling	Adult Black-necked Stilt
e Rooted Plants - Receptor	14 (3)	30 (5)	3 (2)	0
f Water - Receptor	5 (2)	5 (2)	0	5 (2)
g Non-rooted Plants - Receptor	33 (7)	18 (3)	2 (1)	0
h Herbivores - Receptor	41 (6)	35 (5)	79 (8)	38 (5)
i Carnivores(1) - Receptor	7 (2)	7 (2)	16 (5)	7 (3)
j Detritus/Microbes - Receptor	0	1 (1)	0	5 (1)
k Detritivores - Receptor	0	2 (1)	0	38 (5)
l Carnivores(2) - Receptor	0	2 (1)	0	7 (3)
m Offsite Food Sources	0	0	0	0

[a]For the seasonally Wet Areas. Also applicable to FRP seasonally wet areas in the northern ponds.

[b]For ponds that will be wet all year (southern ponds).

[c]Uniform distribution, therefore range is given.

[d]In cases where two routes of selenium supply exist, their ratio of supply is defined.

[e]Percent of total diet from each compartment.

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Table 3-4
TRANSFER AND DIET FACTORS FOR SIMPLIFIED SELENIUM
TRANSFER DIAGRAM FOR EARED GREBE AND MOSQUITOFISH
(Standard Deviations are in Parentheses)

	Past Condition	Flexible Response	Onsite Disposal 1[a]	Onsite Disposal 2
Sediment Conc. (mg/kg d.w.)	7 (7)	7 (7)[b]	3(2)	1.5 (1)
Surface Water Supply (mg/l)	0.3	0	0	0
Transfer Factors				
1 Sediment - Water[c]	0.0003-0.002	0.0003-0.002	0.0003-0.002	0.0003-0.002
2 Water - Non-rooted Plants	187 (22)	500 (50)	500 (50)	500 (50)
3 Non-rooted Plants - Herbivores	2.2 (0.8)	4.0 (2.0)	4.0 (2.0)	4.0 (2.0)
4 Herbivores - Carnivores	0.7 (0.3)	1.5 (0.5)	1.5 (0.5)	1.5 (0.5)
Relative Supply Factors[d]				
a Surface Water Supply - Water	100	0	0	0
b Sediment - Water	0	0	0	0

DIET FACTORS[e] FOR
PAST CONDITIONS, FLEASIBLE RESPONSE, AND ONSITE DISPOSAL

	Western Grebe	Mosquito-fish
c Water - Receptor	10 (5)	N/A
d Carnivores(1) - Receptor	90 (5)	N/A

[a]For the seasonally wet areas. Also applicable to FRP seasonally wet areas in the northern ponds.

[b]For ponds that will be wet all year (southern ponds).

[c]Uniform distribution, therefore range is given.

[d]In cases where two routes of selenium supply exist, their ratio is defined.
N/A = Not applicable - see text.

[e]Percent of total diet from each compartment.

Table 3-5
TRANSFER AND DIET FACTORS FOR SIMPLIFIED SELENIUM TRANSFER DIAGRAM FOR SAN JOAQUIN VALLEY KIT FOX
(Standard Deviations are in parentheses)

	Past Condition	Flexible Response	Onsite Disposal 1[a]	Onsite Disposal 2
Sediment Conc. (mg/kg d.w.)	3 (2)	3 (2)[b]	3(2)	1.5 (1)
Surface Water Supply (mg/l)	0.3	0	0	0
Transfer Factors				
1 Soil - Terrestrial Plants	10 (5)	10 (5)	10 (5)	10 (5)
2 Terrestrial Plants - Herbivores	.3 (.3)	.3 (.3)	.3 (.3)	.3 (.3)
3 Herbivores - Carnivores	4 (2)	4 (2)	4 (2)	4 (2)
Diet Factors[c]				
a Herbivores - Receptor	22.5 (20)	9 (5)	9 (5)	9 (5)
b Carnivores - Receptor	2.5 (2)	1 (1)	1 (1)	1 (1)
c Offsite Food Sources	75 (25)	90 (10)	90 (10)	90 (10)

[a]For the seasonally wet areas. Also applicable to FRP seasonally wet areas in the northern ponds.

[b]For ponds that will be wet all year (southern ponds).

[c]Percent of total diet from each compartment.

NON-PISCIVOROUS AQUATIC BIRD EXPOSURE PATHWAY

Aquatic Pathway

One of the three pathways of selenium transfer into and through the food chain is the aquatic pathway. Recent studies by LBL (1986) have indicated that selenium flux from sediments to "clean" water (less than 2 µg/l) will result in a concentration in the water column selenium concentration of between approximately 2 and 15 µg/l. They have found at KR that introduction of clean water resulted in a water column concentration of less than 10 µg/l. Further, their laboratory experiments suggest that contaminated sediments can cause up to a 15 µg/l increase in water column concentration. The selenium concentrations in the water to be applied to KR will be less than 2 µg/l. Based on these data, we expect the selenium in the water column to be between 2 and 15 µg/l. The empirical relationship between the concentrations of selenium in sediments in the Flexible Response Plan (7 mg/kg) and those expected in the water column (2-15 µg/l), was used to calculate a range of transfer factors of 0.0003-0.002. This range of transfer factors was used in the model to calculate water column selenium concentration for cleanup alternatives. Unlike other transfer factors it is described with a uniform distribution rather than the log normal distribution associated with the other transfer factors. Therefore, no variance component is given.

The transfer factor between water and non-rooted plants at KR (Nitella and aufwuchs) was calculated to be 187 ±22 using paired observations of selenium concentrations in water and unrooted plants. This transfer factor reflects the relationship at a water selenium concentrations very much higher than is expected to result from either cleanup alternative. Since the uptake and metabolism of selenium probably does not have a linear relationship with concentrations in water, a transfer factor appropriate for the predicted range (2-15 µg/l) was derived from literature reviewed by Lemly (1985a) and Ohlendorf, et al. (1986). The same procedure was followed for derivation of other transfer factors in the aquatic food chain. Transfer factors derived from literature were generally about two to three times higher than those observed in high water selenium concentrations at KR.

Benthic Pathway

The benthic epifauna and infauna can acquire selenium from overlying water and from sediments with which they live in close association. We assumed in our simplified selenium transfer diagram that sediments would be the major source of selenium available to benthic organisms since the concentrations in water are expected to decline substantially in both

alternatives. Since the sediment selenium concentrations are not expected to change in the flexible response alternative and change by only a factor of two to three (versus 10 to 100 times in the water for the aquatic pathway), the empirical relationship between selenium concentrations in the various selenium compartments (e.g., sediment, detritus, etc.) at KR was used to determine the selenium transfer factors.

Rooted Plant Pathway

Rooted aquatic and semi-aquatic plants at KR can potentially acquire selenium from both sediment/soil, via the root/rhizome system, and water, via the leaf tissues. There are no definitive studies describing selenium uptake pathways of aquatic plants (Denny 1980). However, studies involving other aquatic angiosperms and compounds other than selenium suggest that aquatic plants are somewhat opportunistic and will acquire ions from the most bio-available source (McRoy and Barsdate 1970, Nicholas and Keeney 1976, Faraday and Churchill 1979, Brinkhuis et al. 1980, Denny 1980, Kenworthy et al. 1982). Sculthorpe (1967) indicates that tissues typically associated with nutrient translocation are reduced or vestigial in most aquatic angiosperms. Based on these studies, we have inferred an approximate ratio of sediment to aquatic sources of selenium uptake by aquatic plants of 1:3. This is shown in Table 3-3 as a "relative supply factor." These studies indicate that metal ions are not transported from sediments to the water column.

Diets of Key Non-Piscivorous Aquatic Bird Species

An estimate of selenium exposure requires a quantification of the fraction of the whole diet of each organism (diet factor) that is contributed by each compartment contained in the simplified selenium transfer diagram. A review of scientific literature was conducted for each species to quantify their food habits (Martin et al. 1951, Pough 1951, Johnsgard 1975, Bellrose 1976). Qualitative data of Ohlendorf, et al. (pers. comm.) support the estimates of diet factors given in Table 3-2. The key to the labels associated with each value in Table 3-2 is given in Figures 3-7 through 3-9.

Some species had dietary preferences that changed very little with life stage or season. The preferences of other species changed substantially with season or life stage. Ranges of food preferences were developed, as appropriate for the specific life stage, sex, etc., of the four species.

This procedure for determining these values is imperfect since the key species probably do not distinguish between, for instance, epiphytic herbivores and carnivores. In such

situations, where selection is approximately a function of their relative numbers and availability, the ratio of the relative mass of the two groups was used to estimate the ratio of their consumption. Mass units were used because selenium data are so expressed. For example, if it was determined from the literature that the diet of species X is 50 percent (by weight) epiphytic invertebrates, data from KR would be used to determine their relative availability. Data indicate that the ratio (mass) of herbivores to carnivores is approximately 5:1. The dietary percentage would be determined using the 5:1 ratio, as follows:

Herbivores $\frac{5}{6} \times 0.50 = 0.42$

Carnivores $\frac{1}{6} \times 0.50 = 0.08$

Estimates of the variability in diet and confidence in estimates of mean dietary percentages are reflected in the variance term associated with each mean.

The simplified selenium transfer diagram also provides for consumption of uncontaminated food from areas adjacent to KR. This component of the diet was minimized so that "worst case" estimates of selenium exposure would be obtained.

FISH/PISCIVOROUS BIRD PATHWAY

The fish/piscivorous bird pathway was developed following a similar procedure to that used in the development of the non-piscivorous aquatic bird exposure pathway. The fish/fish-eating bird pathway described in Figure 3-5 contains only the aquatic pathway and not the benthic or rooted plant pathway. The reasons for omitting the benthic pathway are that mosquitofish do not use the benthos, and introduction of fish that do use the benthos is not anticipated at KR. The rooted plant pathway is also not included in the simplified selenium transfer diagram for the fish/piscivorous bird exposure pathway because rooted plants are not a component of the fish/piscivorous bird food chain.

Fish

Mosquitofish are included in the aquatic carnivore category because of their functional similarity to other members of the category at KR. Mosquitofish under past conditions have been found at KR to have similar selenium levels as that of other carnivores such as odonate larvae (USBR 1986a, LBL 1986). Although mosquitofish consume some non-rooted plants, their selenium concentrations can be described as a function of selenium levels in herbivores. Therefore, the same transfer factors are used in the fish/piscivorous bird

pathway as were developed for the non-piscivorous aquatic bird pathway.

Birds

The eared grebe was selected as the ultimate receptor in the fish/piscivorous bird pathway. The eared grebe does not search for food over a broad habitat range and, therefore, it was assumed that all of its food was obtained at KR and that fish constitute all of its diet. Eared grebes also feed on other types of organisms at KR such as soldierfly larvae. However, since the intent is to model exposure of a fish-eating bird, fish were emphasized in the model.

TERRESTRIAL PATHWAY

The San Joaquin kit fox population near KR is currently under study since little is known of their numbers, feeding range and feeding habits. However, it is possible to estimate exposure based on existing information (although standard deviations associated with transfer and diet factors are large).

The simplified selenium transfer diagram for the kit fox is given in Figure 3-9. The transfer factors were derived from data in USBR (1986a) and are given in Table 3-5. Diet factors were estimated based on the relative abundance of herbivorous and carnivorous mammals which appear to constitute most of the diet of the kit fox. The fraction of the total diet obtained at KR was calculated by dividing the total estimated kit fox range (1,280 acres) into the upland area at KR (350 acres). The fraction obtained at KR is estimated to decline in the future as management practices reduce kit fox feeding habitat. Uptake of selenium from water drunk at KR is not included and is expected to be small given the low dissolved selenium levels expected and the small quantity of water consumed relative to prey.

Chapter 4
TOXICOLOGY OF SELENIUM

INTRODUCTION

The purpose of this analysis of selenium toxicity is to put into context the selenium exposure estimates generated in Chapter 5. Available data concerning selenium toxicity to key organisms at KR are reviewed to identify harmful levels of dietary selenium intake. This analysis is compared with the results of selenium exposure estimates for each cleanup alternative in Chapter 5.

ENVIRONMENTAL SOURCES

Selenium in the environment, its occurrence, biogeochemistry, and toxicity have been reviewed extensively (Rosenfeld and Beath 1964, Shamberger 1981-1983, Zingaro and Cooper 1974, Wilber 1980, NRC 1976, 1980, 1983, Adriano 1986, Eisler 1985). Selenium may become available to bioaquatic and terrestrial organisms from the weathering of rocks and soils (Rosenfeld and Beath 1984) and the activities of man (USEPA 1980). Selenium in the environment may occur in numerous chemical forms due to the processes of oxidation and reduction and biologically mediated transformations. However, the various forms of selenium are not distinguished in this risk assessment because the toxicity evaluation includes all forms of selenium. This approach is conservative relative to selenium toxicity because most data collected at KR describe total selenium concentrations. The risk characterization also uses total selenium concentrations.

BIRDS

SELENIUM TOXICITY

Excessive selenium has produced toxicity symptoms in numerous animal and human populations. The range of health problems observed in birds is discussed in the following section. Extensive reviews of selenium toxicity in other animals are found in Rosenfeld and Beath (1964), NRC (1976, 1980), Wilber (1980), USEPA (1980); and human effects are discussed by Shapiro (1973), and National Academy of Sciences (1977).

A summary of pertinent literature references showing a relationship between selenium in avian diet and effects is presented in Table 4-1. A discussion of these findings is presented in the following sections.

SUMMARY OF DOSE-RESPONSE REPORTED FOR AVIAN SPECIES

Dose (ppm)	Chemical Form	Response	Test Organism	Reference
100	Sodium selenite	Mortality of adults; weight loss	Mallard	Heinz, et al. in press
40	Sodium selenite	Reduced chick survival	Chicken	Arnold et al. 1972, 1973
25	Sodium selenite	Mortality of adults	Mallard	Heinz et al., in press
		Depressed body weight - adult	Mallard	Heinz et al., in press
		Reduced egg laying	Mallard	Heinz et al., in press
		Reduced duckling survival	Mallard	Heinz et al., in press
		Lower Radcliffe index	Mallard	Heinz et al., in press
		Depressed body weight - duckling	Mallard	Heinz et al., in press
10	Selenomethionine	Reduced duckling survivial	Mallard	Heinz et al., in press
		Low hatching success	Mallard	Heinz et al., in press
		18% abnormal embryos	Mallard	Heinz et al., in press
		Multiple malformations	Mallard	Heinz et al., in press
		Depressed body weight	Mallard	Heinz et al.
12	Sodium selenite	Lower hatchability	Japanese quail	El-Begearmi et al., 1977
10	Selenomethionine	Low hatching success	Chicken	Poley and Moxon, 1937
10	Sodium selenite	Multiple malformations	Mallard	Heinz et al., in press
10				
7	Selenium selenite	Lowered hatching success	Chicken	Ort and Latshaw, 1978
78	Selenium selenite	Lowered egg production	Chicken	Arnold et al.
7	Selenium selenite	Reduced egg weight	Chicken	Ort and Latshaw, 1978
6	Selenomethionine	No effect on adult or egg production	Chicken	Mosknes, 1983
5	Sodium selenite	Reduced growth	Chicken	Jensen, 1975
5	Sodium selenite	Impaired hatching success	Chicken	Ort and Latshaw, 1978
8	Sodium selenite	Lowered chick survival	Japanese quail	El-Begearmi et al., 1977

Selenium toxicity has been shown to occur in poultry, quail, and mallards from extensive studies dating back to the 1930's. These studies have shown toxic response to dietary ingestion of selenium compounds in an array of manifestations such as reduced growth; reproductive impairment; embryogenic, hatchling, and adult mortality; deformities; and teratogenic effects.

The early studies of chickens receiving selenium in the diet from cereal grains grown in seleniferous soils showed both reduced growth and reproductive impairment to complete failure of hatching (Moxon 1937, Poley et al. 1937, Poley and Moxon 1938, Moxon and Rhian 1943). The selenium content of the grain has been speculated to have contained as much as 10 mg/kg selenium in the form of selenomethionine (Heinz, et al. in press). The chicks produced in some studies (Franke and Tulley 1936) showed severe deformities and high mortality. Recent studies (Ohlendorf, et al. 1986, Ohlendorf et al. in press and Saiki 1986) have correlated diet selenium and low hatchability embryonic deformity and high mortality in wild birds at KR.

The mechanism of selenium toxicity is not well understood (Ohlendorf, et al. 1986). However, researchers have demonstrated various aspects of manifestations of avian selenium toxicity.

Avian Toxicity

Reproductive failure, reduced fecundity, and mortality of adults have been demonstrated using a selenium diet. A study by Heinz, et al. (in press) showed no effect on reproductive success, growth, or survival in mallards with dietary selenium concentrations up to 10 mg/kg. Higher doses of selenium show toxicity. Eleven of 12 adults died on a 100 mg/kg diet and one drake died in the 25 mg/kg diet group. Females on the 25 mg/kg diet showed egg production, fertility, and hatching success diminished significantly when compared to ducks fed with up to 10 mg/kg selenium. Survival of ducklings and 21-day-old body weights were reduced for the ducks receiving 25 mg/kg selenium selenite or 10 mg/kg selenomethionine. Ten and 25 mg/kg inorganic selenium and 10 mg/kg selenomethionine showed teratogenic effects. Eggs containing 22.2 percent abnormal embryos were produced by mallards receiving 25 mg/kg sodium selenite in the diet. Similarly, mallards fed the 10 mg/kg organic selenium compound showed 18.3 percent abnormal embryos with many individuals having multiple malformations such as missing or reduced bills, toes, eyes, and twisted legs.

The Heinz study concluded that selenomethionine was more toxic to mallards than was selenite. Selenomethionine is reported as the major form of selenium in plants; thus, it may pose the greatest threat to herbivorous waterfowl (and carnivorous/omnivorous waterfowl utilizing herbivorous invertebrates/vertebrates for major food items).

Embryonic Effects

Selenium compounds introduced into chick embryos produced a range of deformities due to necrosis of brain and spinal cord tissues, the optic cups and vesicles, and in limb tissues (Gruenwald 1985). Embryonic malformations such as twisted necks and legs, missing appendages, absent or deformed beaks, protruding eyes, and edema were observed when 15 mg/kg selenium were introduced to the diet of chickens (Poley, et al. 1937, Franke, et al. 1936, Franke and Tulley 1936). Chickens fed 7 to 9 mg/kg selenium or sodium selenite produced embryos with edema of the head and neck (Ort and Latshaw 1978, Arnold, et al. 1973). Mallards fed 10 mg/kg selenium as selenomethionine or sodium selenite produced abnormal embryos (Heinz, et al. in prep.). The abnormalities noted in the embryos included stunted growth, swollen necks, hydrocephaly, and malformations such as reduced or absent lower bill, spoon-shaped bill, missing toes, twisted legs, and small or missing eyes. Control group abnormalities were limited to minor bill defects, stunting, and swollen necks.

Shell quality as measured by the Radcliffe Index was poorer and duckling weight at birth was lower from eggs produced by mallard hens fed 25 mg/kg selenium (Heinz, et al. in press).

Hatching Success

Hatching success of fertile eggs has been considered the most sensitive measure of reproductive effect of selenium (Heinz, et al. in press). Ort and Latshaw (1978) identified 5 mg/kg selenium (sodium selenite) as "borderline toxic" in chickens due to depression of hatching rates. Other studies of chickens (Ort and Latshaw 1978, Arnold, et al. 1972, 1973) and Japanese quail (El-Begearmi, et al. 1977) showed reduced hatchability success when 7 to 9 mg/kg and 6 to 12 mg/kg selenium doses respectively were fed in the diet. Mallards fed up to 25 mg/kg selenium (sodium selenite) showed no statistically significant decrease in hatchability, although some decline was noted at 25 mg/kg (Heinz, et al. in press).

FINDINGS

The limited information demonstrating selenium toxicity in avian species shows that selenium concentrations of 5 mg/kg

dry weight in the diet may have chronic toxic effects on chickens. The results of Heinz's study with mallards showed that a 10 mg/kg concentration of selenomethionine results in reproductive impairment or embryonic deformities.

There is a lack of wild bird studies using test species birds similar in ecological needs to the receptors at KR. Avian species at KR may have feeding habits, metabolic activities, reproductive cycles, and other important factors that would cause them to adversely respond to either higher or lower levels of selenium in the diet than observed in the few studies conducted to date with quail, ducks, and chickens.

Other complicating factors are related to the selenium transformations in the environment and food chain. For example, different bird species will be exposed to various ratios of inorganic and organic selenium (and subsequent toxic effects) depending upon diet preferences and prey food availability. There are no data available to estimate the effect of this unknown.

Based on existing information, the range of harmful effect diet selenium concentration is estimated to be 5 to 10 mg/kg. The "safe level" cleanup goal at KR is 3 mg/kg. The USFWS is currently evaluating a dosage of 4 mg/kg in an attempt to define more precisely the relationship between selenium concentrations in wildlife food and wildlife health. USFWS scientists hypothesize that adverse wildlife effects might occur at dosages as low as 5 or 4 mg/kg, but they have measured "background" levels of up to 3 mg/kg total selenium (dry weight) in invertebrates at the Volta Wildlife Area where no biological effects have been observed. On this basis, the USFWS recommends 3 mg/kg for wildlife food pending conclusion of their field and laboratory research.

MAMMALS

Dose response relations showing toxicity from diet sources have not been reported for wild mammal species. Limited studies conducted using dogs and laboratory rats have shown a range of responses. A dosage in the range of 8 to 30 mg/kg dry weight in the diet may result in indications of chronic toxicity in mammals (Wilber 1980). Rats and dogs exposed to dietary levels of 5 to 10 mg/kg dry weight selenium could be expected to show evidence of chronic toxicity (Anspaugh and Robinson 1971). Indications of chronic toxicity such as liver changes and heart, kidney, and spleen effects resulted from dietary selenium levels of 1.4 to 3.0 mg/kg dry weight.

In the study of post weanling rats fed 1.6 to 11.2 mg/kg selenium, Halvorson et al. (1966) observed no significant

effect on growth by selenium concentrations of 1.6 to 4.8 mg/kg. A diet of 6.4 mg/kg dry weight of sodium selenite or of seleniferous wheat caused significant growth depression, and death occurred in the post-weanling rats after the fourth week of the experiment at levels of 8.0 to 11.2 mg/kg. Spleen and pancreas enlargement were observed on the 6.4 and 8-mg/kg diet, while liver weight was reduced when 9.6 or 11.2 mg/kg selenium were fed. Earlier studies have shown a toxic response in rats fed 5 mg/kg in the diet (Moxon 1937, Franke and Painter 1938).

As with birds, there is a lack of toxicological information on species similar to receptors at KR. Based on existing information for other mammals, the range of harmful effect diet selenium concentration is estimated to be 2 to 5 mg/kg.

FISH

There are very little data on which to base a direct estimate of a no adverse effect level of dietary selenium on fish (Hodson and Hilton 1983). Fish, however, are sensitive to direct exposure to selenium in water.

In the development of ambient water quality criteria for selenium, EPA (1980) summarized a database of 23 studies of eight freshwater fish species. The acute toxicity (96-hour LC50) values ranged from 620 to 28,500 µg/l for the bluegill. Lower 96-hour LC50 concentrations of 2,100 and 5,200 µg/l were determined for fathead minnow fry and juveniles, respectively. During acute testing it was noted that some species become more sensitive with increased length of exposure beyond 96 hours. EPA determined a freshwater final acute value of 263 µg/l. The criterion to protect freshwater aquatic life was set at 35 µg/l as a 24-hour average. This concentration is above expected water selenium levels at KR in the future.

Bioaccummulation of selenium in the food chain has been implicated as the cause of reduced fish populations (Lemly 1985a, 1985b, Finley 1985, Hilton, et al. 1980). An example from the effect of bioaccumulation was demonstrated at Belews Lake by Finley (1985) where mayfly nymphs (<u>Hexagenia limbata</u>) fed to bluegills caused pathological and behavioral changes. Fish at Belews Lake are surviving on a diet containing 5 to 18 mg/kg selenium (wet weight). Studies using rainbow trout (<u>Salmo gairelneri</u>) have shown some adverse response to diets containing as little as 3 mg/kg selenium dry weight (Hilton, et al. 1980). Based on this very limited information, the range of harmful effect diet selenium concentration for fish is estimated to be 3 to 5 mg/kg.

Chapter 5
RISK CHARACTERIZATION

INTRODUCTION

Estimation of the risks to fish and wildlife associated with KR cleanup alternatives is uncertain because of the lack of complete knowledge of the KR ecosystem food chains, uncertainty about the diet of key species, and uncertainty about the transfer factors which describe the biomagnification of selenium between food chain components along exposure pathways. Estimates of uncertainty for diet factors and transfer factors for the key species were presented in Chapter 3.

The uncertainty associated with each diet and transfer factor is compounded with other uncertainties in the estimation of exposure level and increases the variability in a final estimate of exposure. The risk characterization provides estimates of this total variability through the use of a Monte Carlo simulation model.

KESTERSON MONTE CARLO MODEL

A Monte Carlo model is constructed by first building a conceptual model of the system. For KR, the model consists of a simplified selenium transfer model developed for each of the key species. These models are described in Chapter 3. The model simulates the selenium concentration in each compartment along an exposure pathway by multiplying the selenium concentration in the previous compartment by the appropriate transfer factor. Key species diet selenium concentration is calculated by weighting each component of the diet by the appropriate diet factor. Boundary or initial conditions for the model are those selenium concentrations in KR sediments or surface water after implementation of a clean-up alternative.

Each estimated transfer factor and diet factor has an associated standard distribution, either uniform or lognormal. The lognormal distribution is used to represent uncertainty in the transfer and diet factors because it is a common distribution of selenium concentration data observed in nature. In addition, the lognormal distribution has several statistically desirable properties, such as estimating only positive values. It is a skewed distribution that produces rare large values more often than does the normal distribution. The best estimate of the transfer and diet factors is taken as the mean of the distribution and the uncertainty is expressed as a standard deviation or range.

The model is run several hundred times with each iteration using new values for transfer and diet factors drawn randomly from the assumed distribution for each factor. The results of each simulation are tabulated and used to create an empirical frequency distribution of predicted selenium concentrations in the diet of each key species.

Simulations were run for each cleanup alternative for each key species. The model was also run under past conditions with the application of drainwater to KR.

DISCUSSION

MODEL RESULTS

Figures 5-1 through 5-3 summarize results for each of the cleanup alternatives. The figures show the range of predictions of selenium concentration in the diet of key species. Figures 5-4 through 5-10 show the results using historic conditions with application of drainwater. For any combination of cleanup alternative and key species, the 50-percent probability level represents predicted diet selenium concentration resulting from the mean transfer and diet factors for that particular condition. The uncertainty of the exposure estimate is shown by the probability distribution about the mean.

As an example, consider the results of predictions of mallard exposure under the FRP. The 50-percent probability level represents a diet selenium concentration of about 5 mg/kg (from Figure 5-1). Therefore, 50 percent of the predictions of diet selenium concentration are less than 5 mg/kg, or based on the selenium transfer model and on the uncertainty of transfer and diet factors, the FRP has about a 50-percent chance of resulting in a mallard diet selenium concentration of less than 5 mg/kg.

MODEL LIMITATIONS

Temporal Context

The exposure estimates for each alternative are based on basic assumptions regarding the steady state relationship between selenium concentration in sediments and the resulting concentration in surface water. Although this relationship is based on existing knowledge of selenium chemistry and field and laboratory experiments, insufficient data have been collected to determine the length of time that will elapse until steady state conditions are achieved. The model results do not take into account the length of time necessary to achieve steady state conditions.

FLEXIBLE RESPONSE PLAN

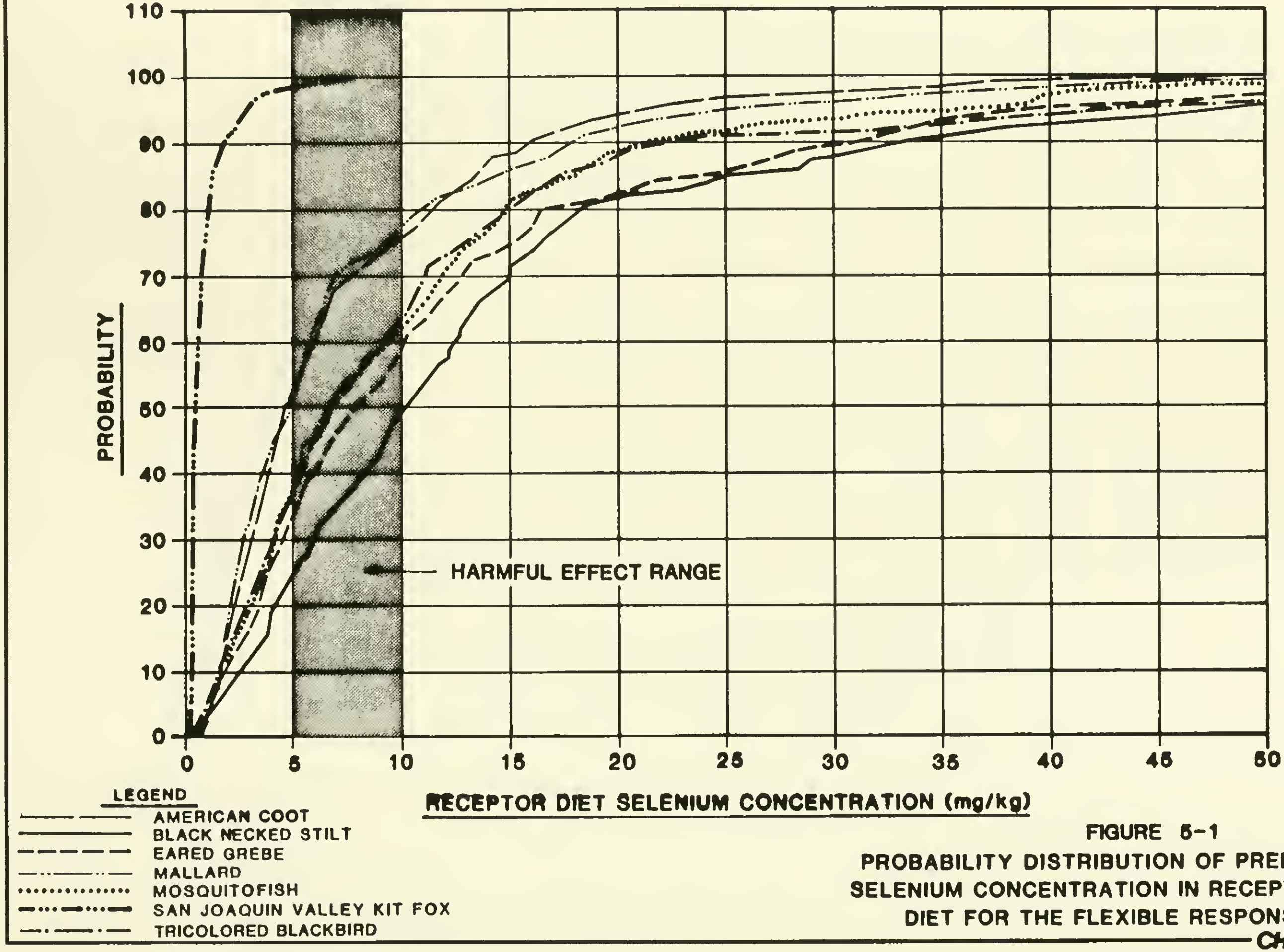


FIGURE 5-1
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

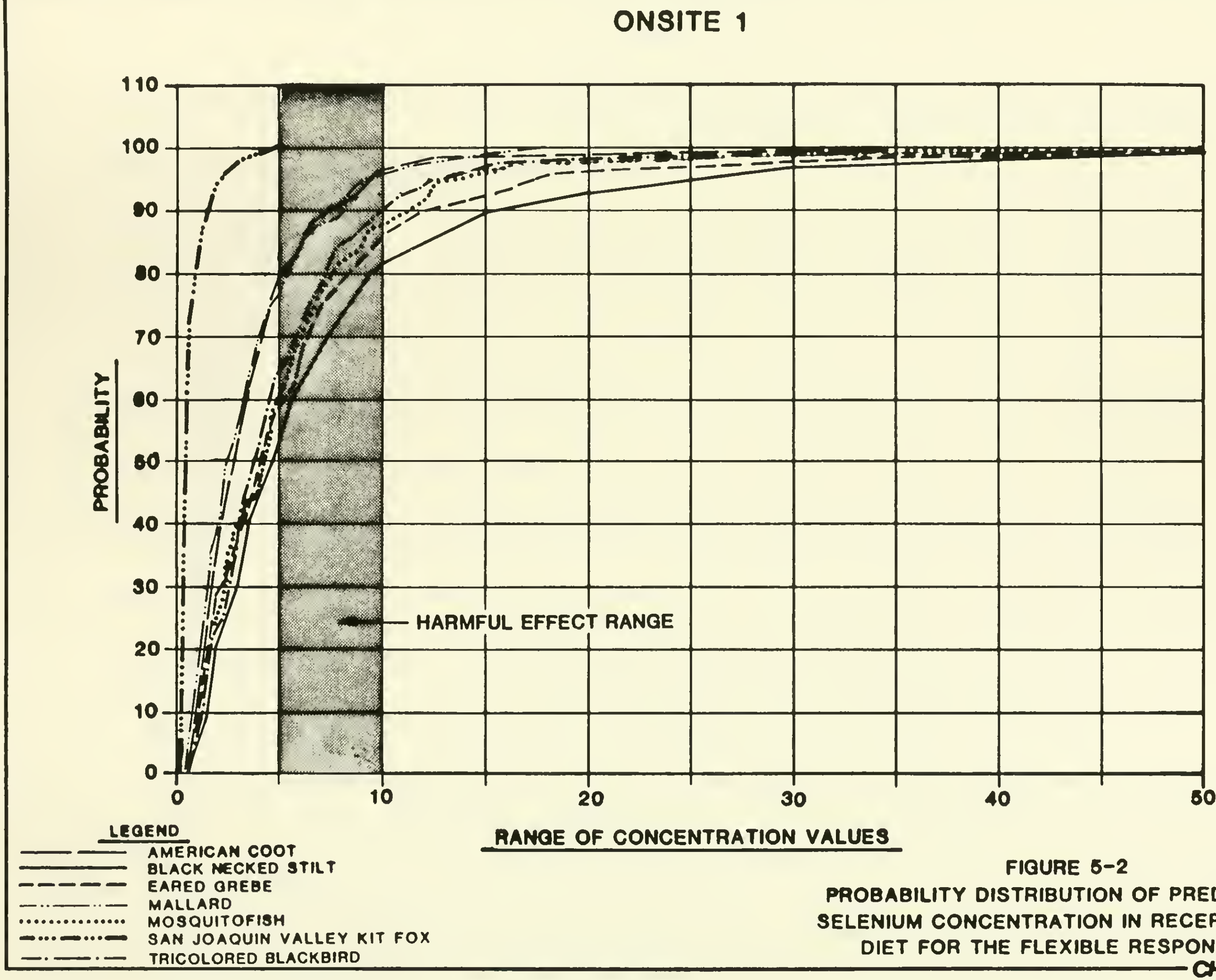


FIGURE 5-2
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

ONSITE 2

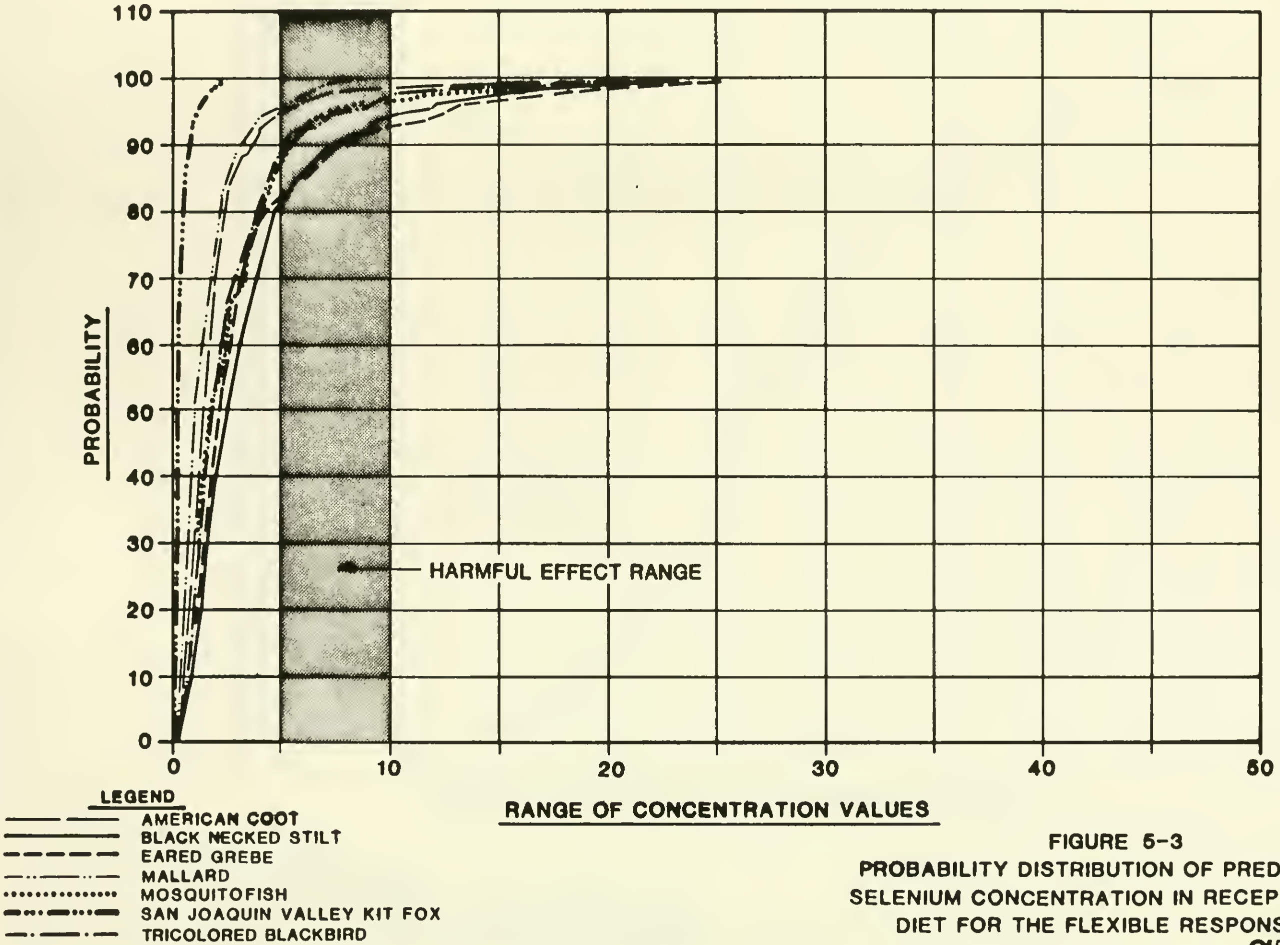
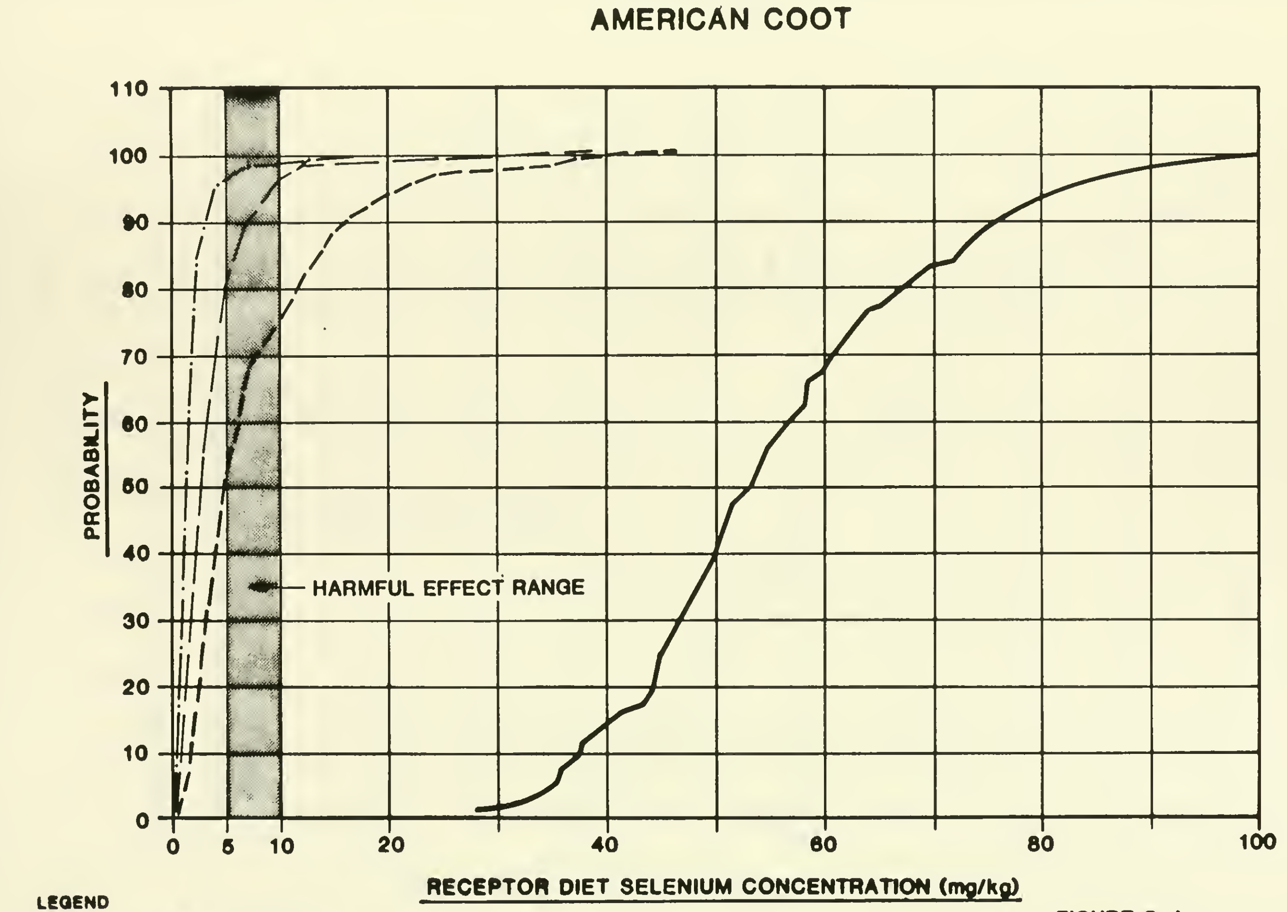


FIGURE 5-3
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL



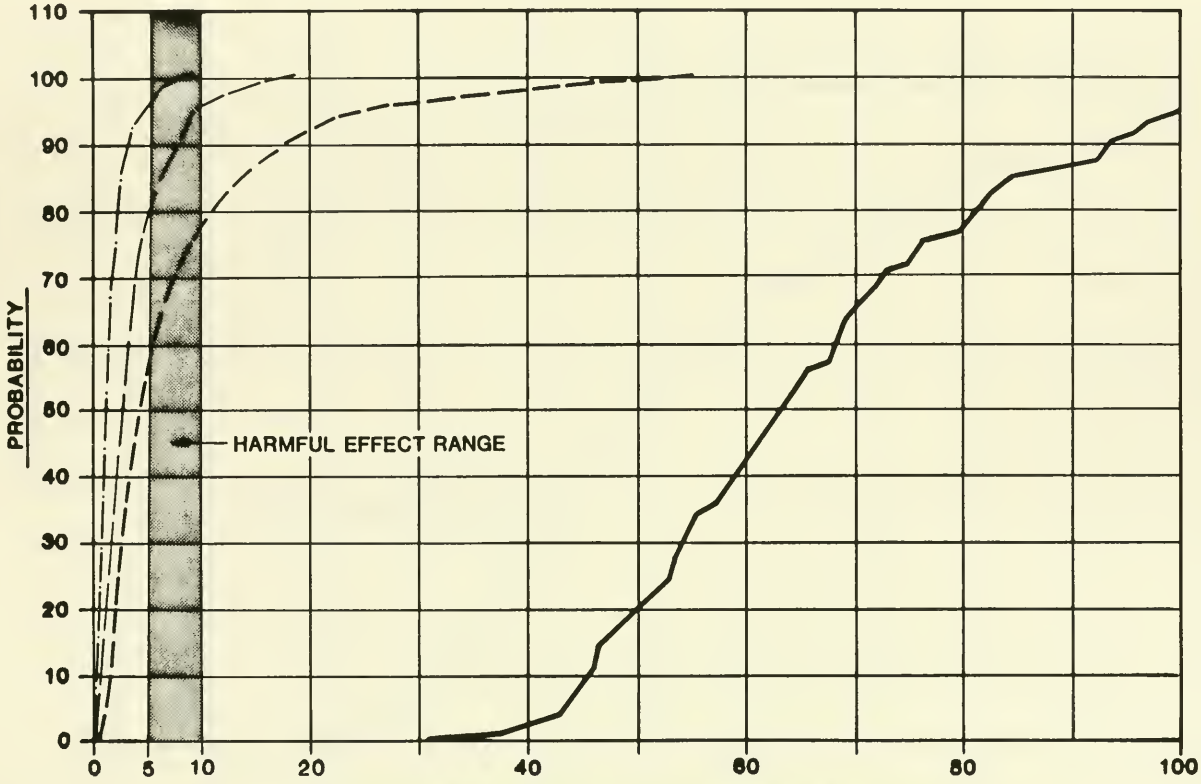
LEGEND

PAST CONDITIONS
FLEXIBLE RESPONSE PLAN
ONSITE 1 - ONSITE DISPOSAL-450,000 CUBIC YARDS
ONSITE 2 - ONSITE DISPOSAL-1,000,000 CUBIC YARDS

FIGURE 5-4
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

MALLARD



LEGEND

PAST CONDITIONS
FLEXIBLE RESPONSE PLAN
ONSITE 1 - ONSITE DISPOSAL-450,000 CUBIC YARDS
ONSITE 2 - ONSITE DISPOSAL-1,000,000 CUBIC YARDS

FIGURE 5-5
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

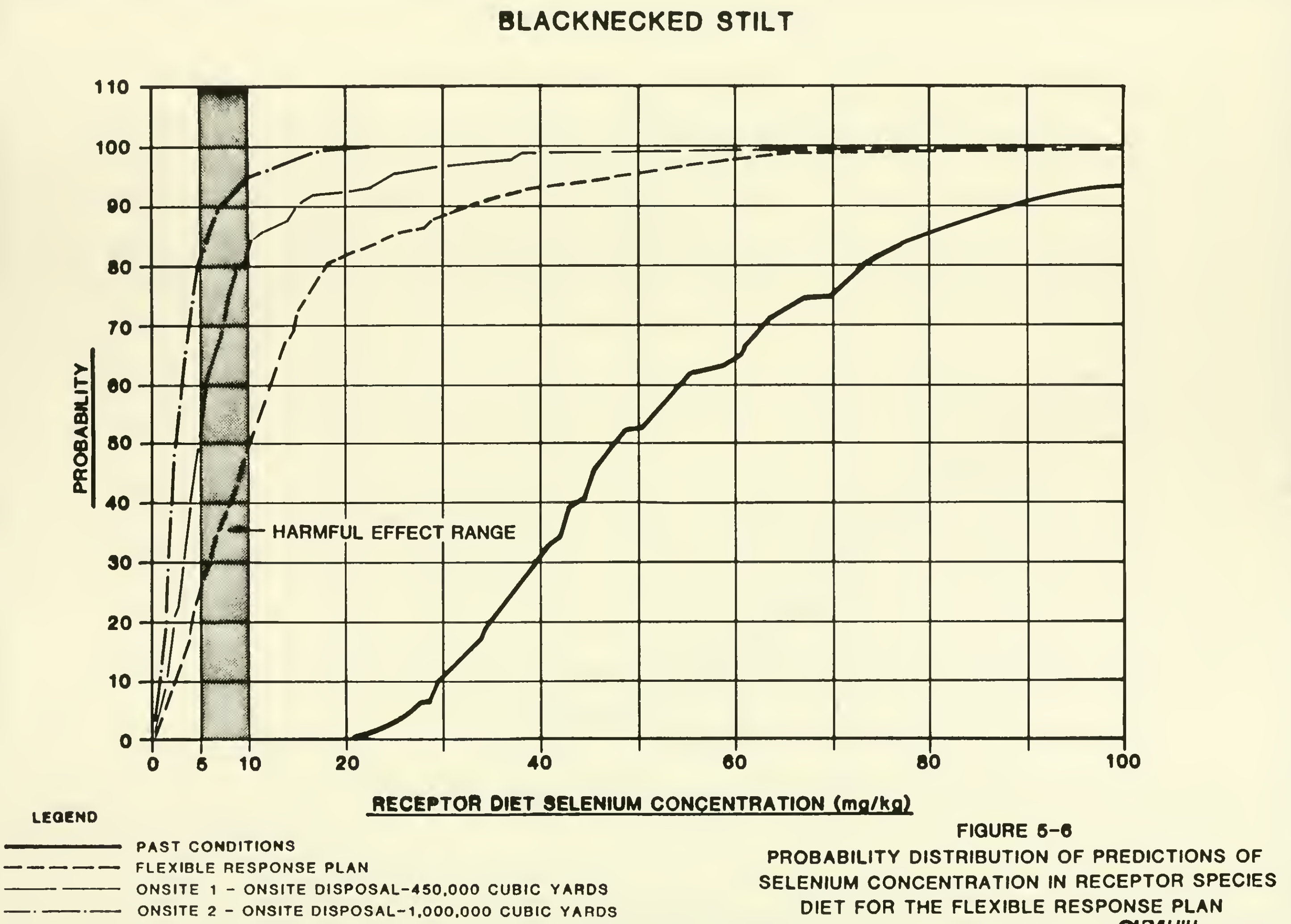


FIGURE 5-6
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

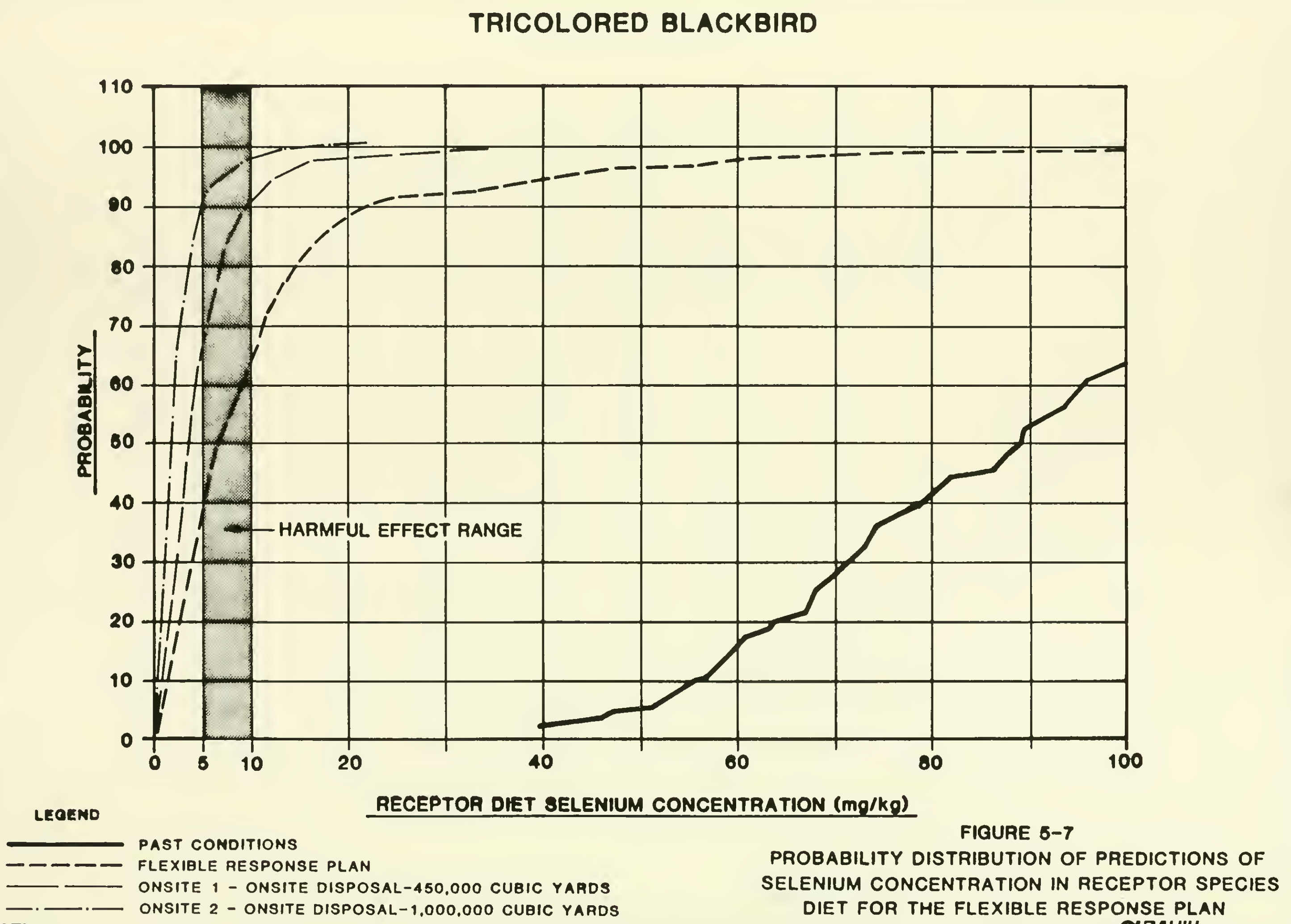


FIGURE 5-7
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

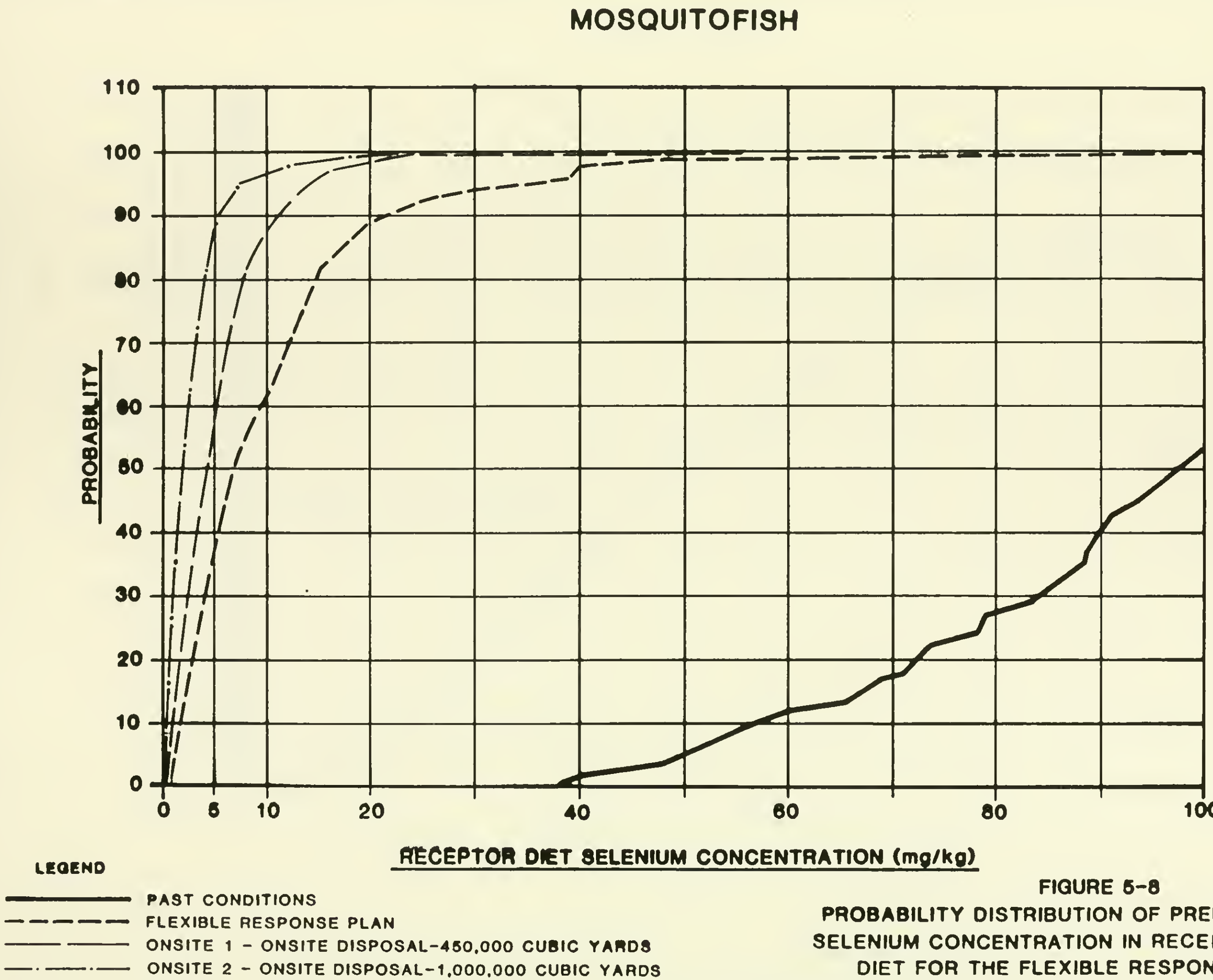


FIGURE 5-8
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

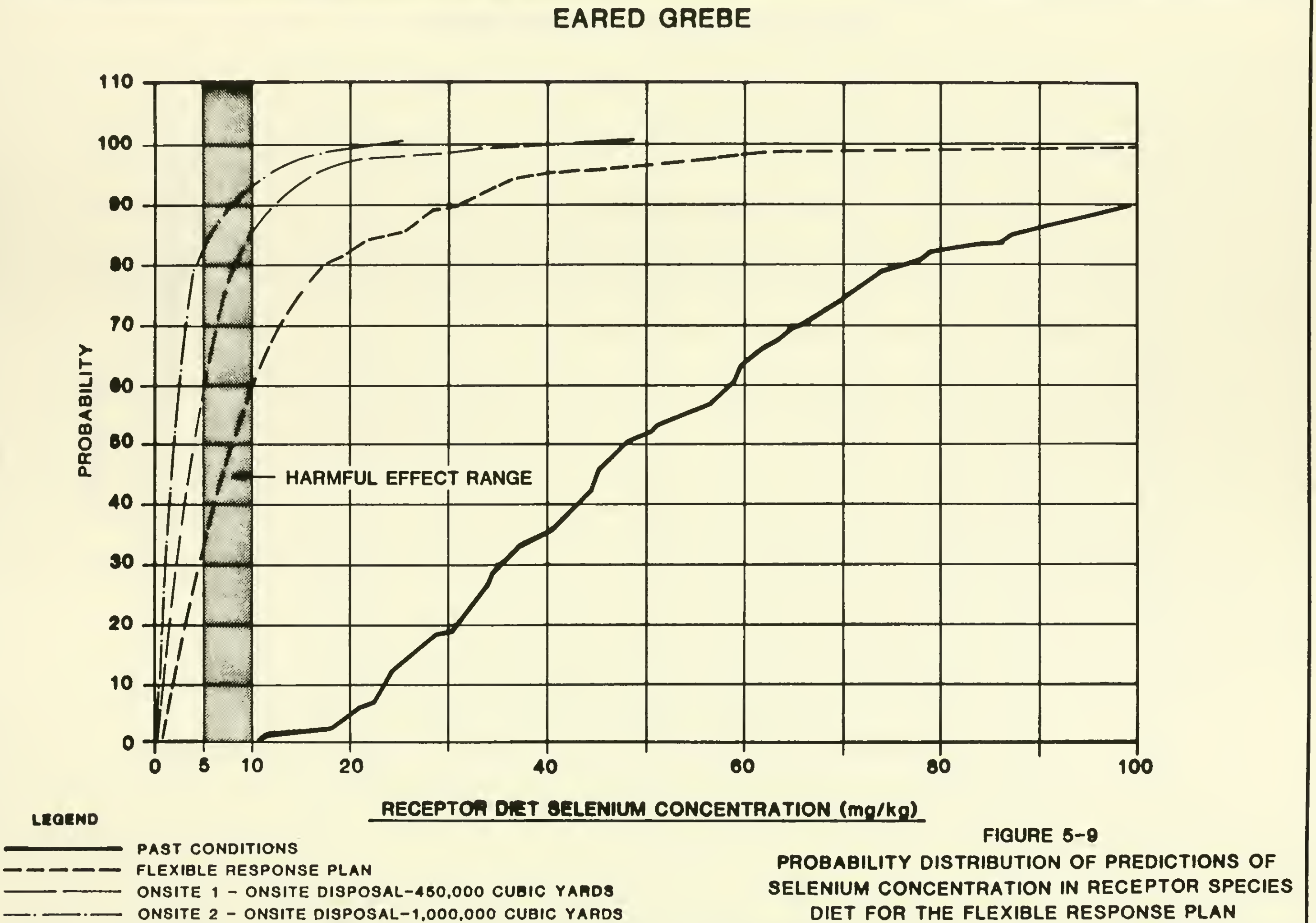


FIGURE 5-9
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

CH2M HILL

SAN JOAQUIN VALLEY KIT FOX

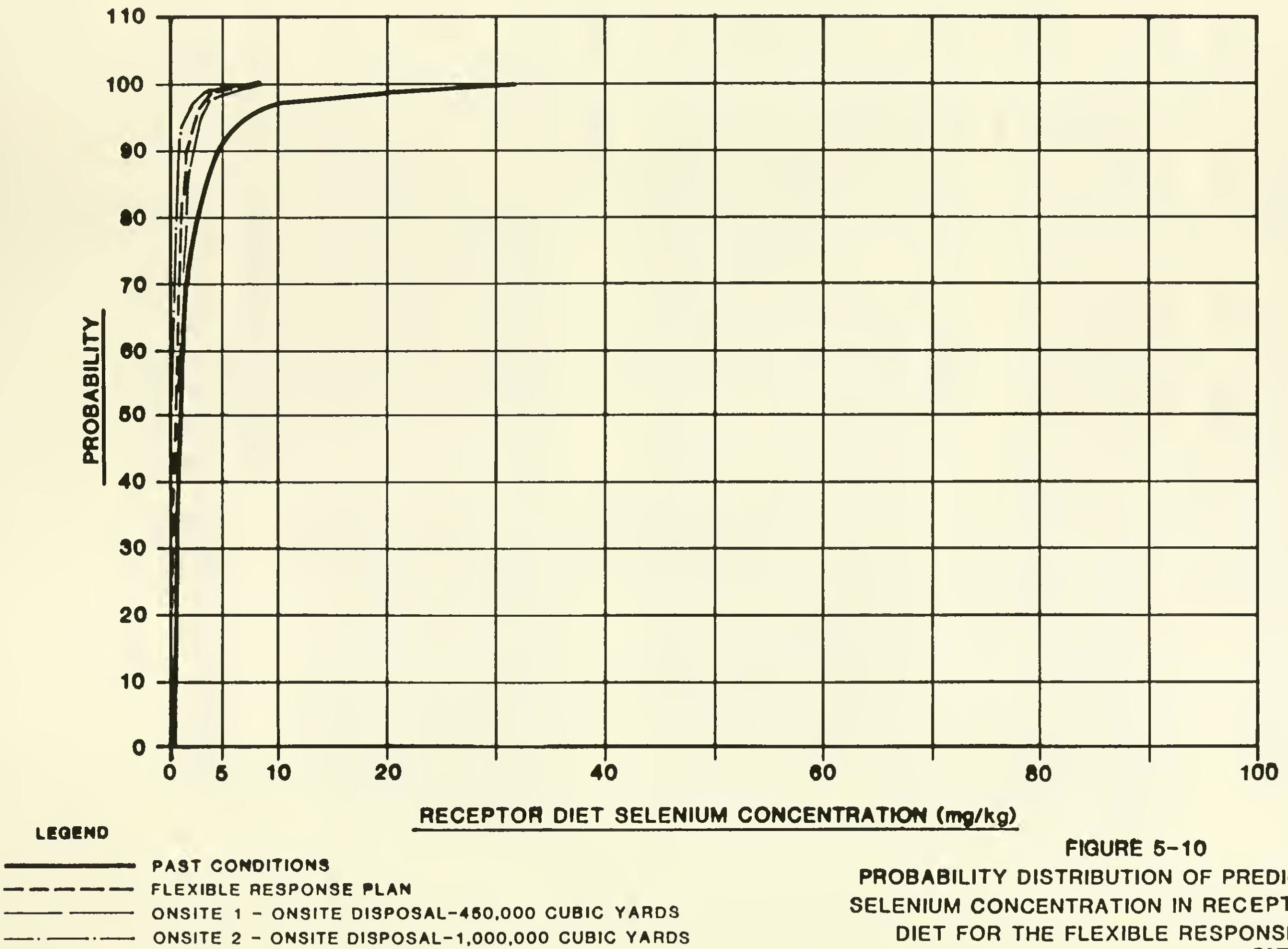


FIGURE 5-10
PROBABILITY DISTRIBUTION OF PREDICTIONS OF SELENIUM CONCENTRATION IN RECEPTOR SPECIES DIET FOR THE FLEXIBLE RESPONSE PLAN

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Accuracy of Predictions

The model does not describe uptake and loss rates of selenium by the components of the exposure pathways; rather, the model uses transfer and diet factors observed in the laboratory and the field. The uncertainty estimates of these factors are based on these observations, but they do not necessarily simulate exact conditions at KR.

Because insufficient information exists to develop quantitative dose-response relationship for diet selenium exposure for the key species at KR, the model results cannot be used to make quantitative estimates of the impact of cleanup alternatives on the exposed population. The toxicity profiles, however, can be used along with model results to determine the uncertainty of the relative safety of cleanup alternatives.

Applicability to Other Organisms

Seven species that are representative of common and important trophic levels at KR were selected for selenium exposure evaluation. The impact of each cleanup alternative on each species can be considered in terms of the fraction of the total population that resides at KR. This is also true for other species that were not directly considered in the analysis since the trophic levels of the seven species are representative of those of a large number of species at KR. In other words, the transfer and diet factors (and associated uncertainties) and, hence, the selenium exposure estimates have broad applicability and are not restricted to the seven species for which they were derived.

Habitat Changes

The model does not address the potential indirect effect of implementation of each alternative on wildlife populations that may result from changes in habitat. As discussed earlier, this is the primary reason why the Immobilization Plan is not addressed in this analysis. Each alternative will affect the habitat of KR to a variable and unquantified extent. For example, implementation of Onsite-2 will reduce tricolored blackbird nesting habitat. Furthermore, diet factors may change in the case of opportunistic organisms in response to changes in food availability brought about by implementation of a particular alternative.

IMPLICATION OF EXPOSURE PREDICTIONS

The toxicity profiles for selenium developed in Chapter 4 indicate the following diet (average total diet) selenium concentrations may result in harmful impacts:

Key Species Group	Harmful Diet Selenium Concentration (mg/kg)	Diet Cleanup Goals (mg/kg)
Birds	5-10	3
Mammals	2-5	3
Fish	5-10	5

Harmful diet selenium concentrations are different than cleanup goals because the harmful levels represent concentrations that are expected to cause harm rather than the more conservative cleanup levels. Table 5-1 shows the percent of diet selenium predictions that are below harmful levels for each key species and for each cleanup alternative.

The risk characterization does not indicate that any of the plans will clearly fail. For avian species, the results for FRP indicate that 40 to 65 percent of the diet selenium predictions will be beneath harmful effect levels. It should be noted that the most recent results of LBL research at KR (LBL 1986) indicate that surface water selenium concentrations may be in the 2- to 5-μg/l range under the FRP. The model results are based on a range of 2 to 15 μg/l. The FRP may therefore have a greater chance of being effective than the modeling results indicate.

The Onsite Disposal Plan-1 shows a greater frequency of below harmful effect predictions than the FRP, 65 to 90 percent. The Onsite Disposal Plan-2 results in the highest frequency of below harmful effect predictions, 85 to 95 percent.

Although the Onsite Disposal Plans show 65 to 95 percent average probability of diet selenium concentrations below the harmful effect level, these plans will be less likely to achieve the more conservative diet cleanup goals. For example, Figure 5-11 shows the relationship between the probability of selenium concentrations in American coot and black-necked stilt diets being less than 3 mg/kg versus residual selenium concentrations in KR soils after onsite disposal. These two species represent the range of predicted responses. The Onsite Disposal Plan-1 appears to have about a 30- to 50-percent chance of achieving receptor diet selenium levels less than 3 mg/kg. The Onsite Disposal Plan-2 has about a 55- to 85-percent chance. To achieve probabilities in the 90- to 100-percent range, soil residuals would have to be less than 0.5 mg/kg. To achieve these residual levels, excavation would have to extend to greater than 6 inches (i.e., excavating the entire site to up to 2 feet).

Table 5-1

PERCENT OF DIET SELENIUM PREDICTIONS THAT ARE BELOW ESTIMATED HARMFUL LEVELS FOR EACH KEY SPECIES AND FOR EACH CLEANUP ALTERNATIVE

	Cleanup Alternative								
Key Species	FRP			Onsite-1[c]			Onsite-2[d]		
Birds - Harmful Effect Level[a]	3	5	10	3	5	10	3	5	10
Mallards	35	50	80	55	75	95	90	95	~100
Coots	30	50	75	55	80	95	85	95	~100
Blacknecked Stilts	10	25	50	30	50	80	60	80	95
Tricolored Blackbirds	20	35	65	40	60	90	70	85	95
Eared Grebes	20	35	60	40	60	85	60	80	90
Mammals - Harmful Effect Level[a]		2	5		2	5		2	5
San Joaquin Valley Kit Fox		90	~100		95	~100		~100	~100
Fish - Harmful Effect Level[a,b]		3	5		3	5		3	5
Mosquitofish		20	35		35	50		70	90

[a] Diet selenium concentration (mg/kg).

[b] Mosquitofish not harmed by these selenium levels although other species may be.

[c] 450,000 cubic yards.

[d] 1,000,000 cubic yards.

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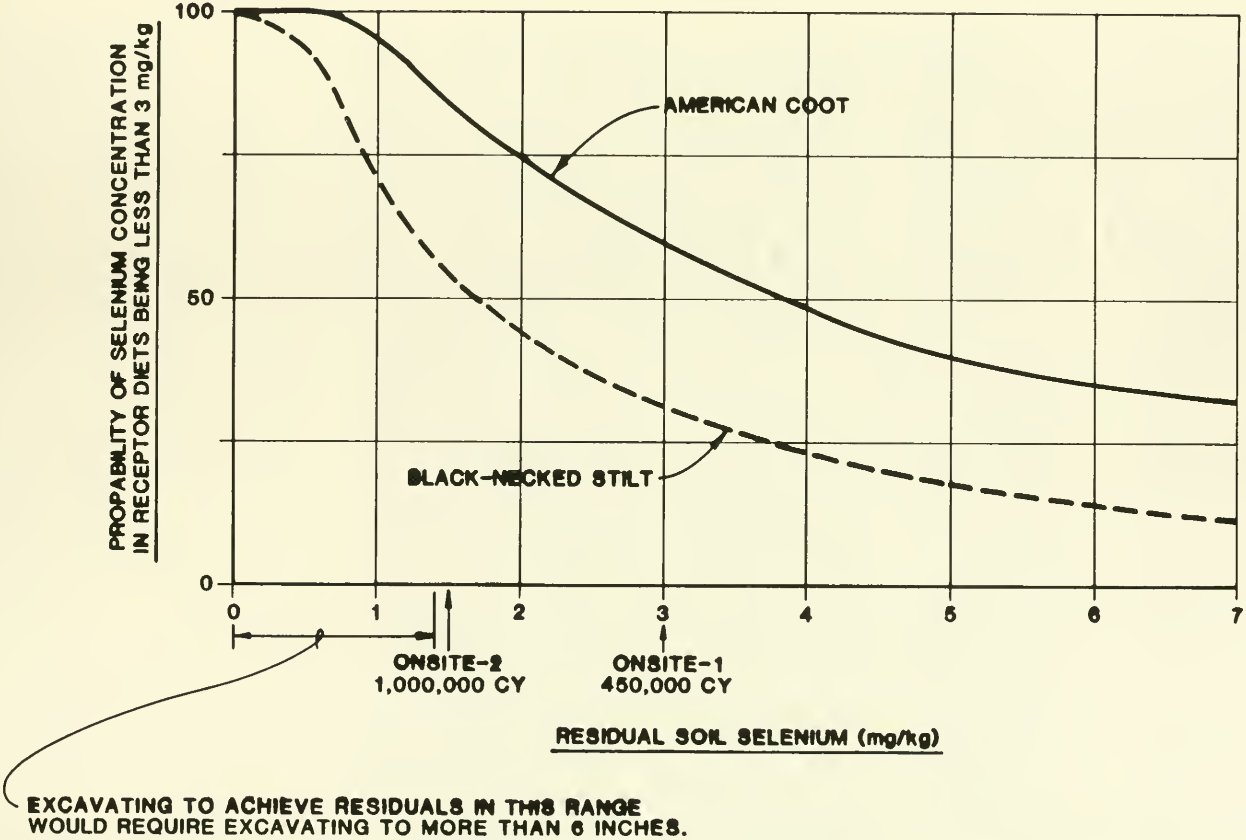

FIGURE 5-11

PROBABILITY OF SELENIUM CONCENTRATION
IN RECEPTOR DIET BEING LESS THAN 3 mg/kg
VERSUS RESIDUAL SOIL SELENIUM CONCENTRATION

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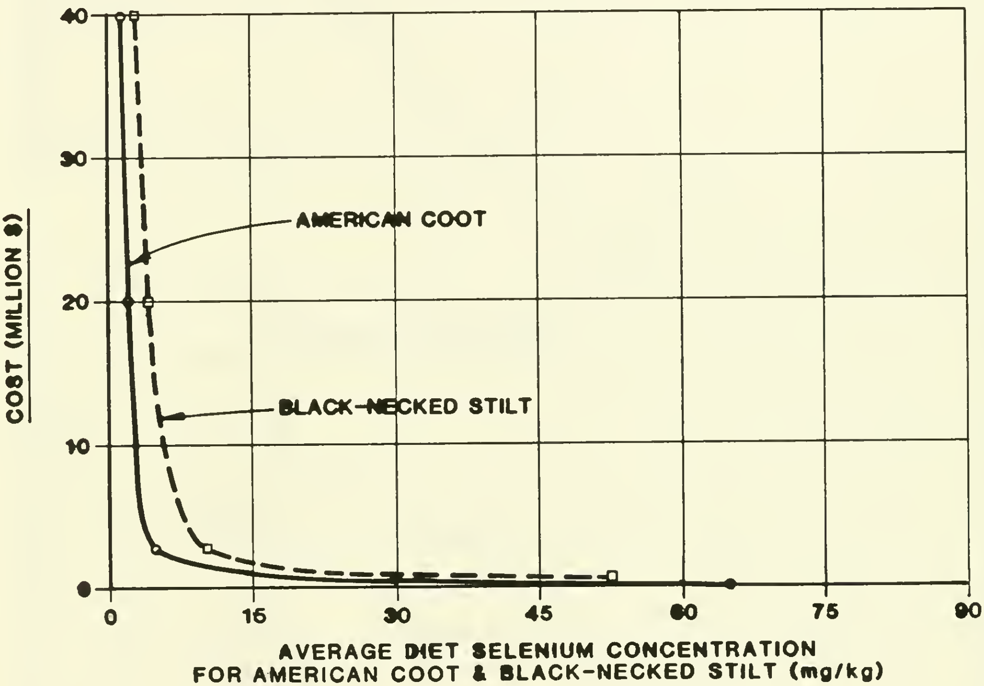
COST VERSUS RISKS

To aid in decisionmaking, costs of cleanup alternatives can be compared to probability of harmful effect occurring. As described in Chapter 4, it is not possible to predict the number of individuals of various species "saved" versus cost under the various cleanup alternatives because quantitative dose response information is not available for the receptor species. Costs can be compared, however, to observations of the total number of birds "lost" in the past (see Table 3-1). Costs can also be compared to predictions of diet selenium concentrations.

Figure 5-12 shows the relationship between diet selenium concentrations for American coots and blacknecked stilts and costs for the three cleanup alternatives and past conditions at KR. This figure shows that termination of drainwater flow into KR and implementation of the FRP will reduce diet selenium concentrations by about 90 percent. However, the FRP still presents risks to wildlife because it may not achieve avian diet cleanup goals.

Figure 5-13 compares the costs of alternative cleanup plans versus "effectiveness" as measured by residual soil selenium concentrations and by predicted average concentrations of selenium in avian diets. As shown by this figure, the FRP is predicted to achieve soil selenium concentrations of 7 mg/kg; 50 percent of the predictions indicate that the FRP can achieve average avian diet selenium concentrations of 8 mg/kg. First year costs of the FRP are $2.5 million. The Onsite Disposal Plan-1, for a first year expenditure of $20 million (8 times that of the FRP), is predicted to achieve soil selenium concentrations of 3 mg/kg (a 57-percent reduction compared to the FRP); 50 percent of the predictions indicate this plan can achieve average avian diet selenium concentrations of 4 mg/kg (a 50-percent reduction compared to the FRP). The Onsite Disposal Plan-2, for a first year capital expenditure of $40 million (16 times that of the FRP), is predicted to achieve soil selenium concentrations of 1.5 mg/kg (a 79-percent reduction compared to the FRP); 51 percent of the predictions indicate this plan can achieve average avian diet selenium concentrations of 2.5 mg/kg (a 69-percent reduction compared to the FRP).

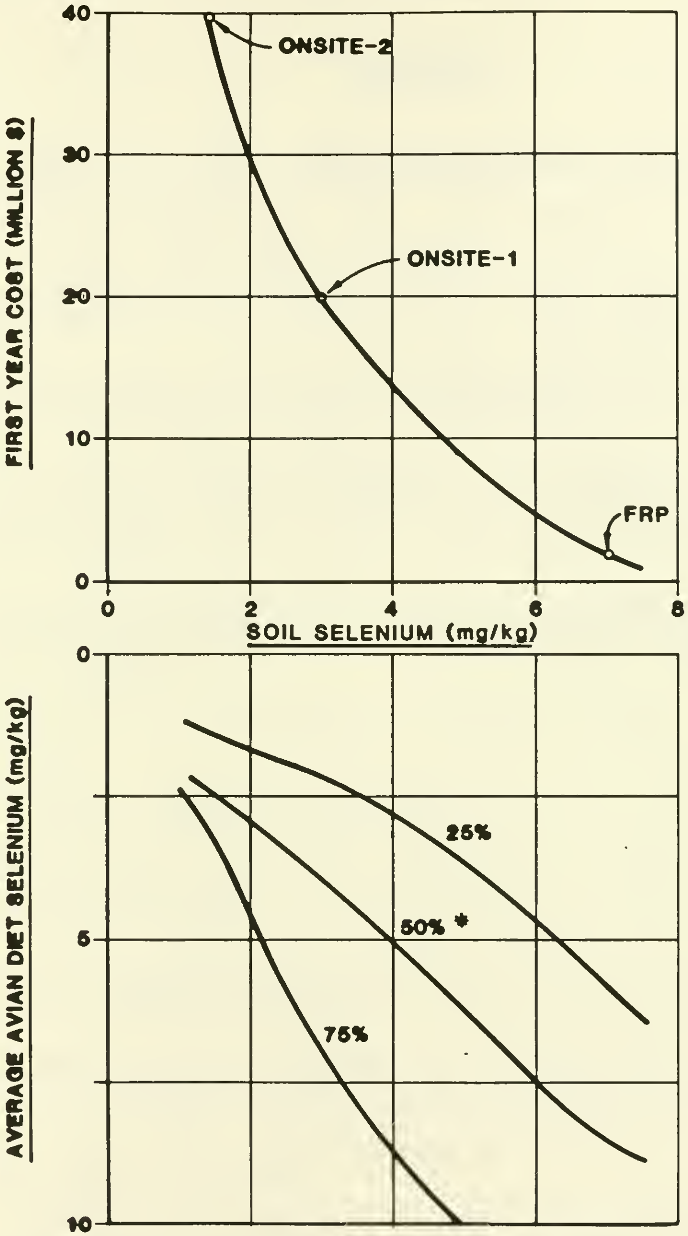


COSTS (DOLLARS)

FRP: 2.5 MILLION
ONSITE-1: 20 MILLION
ONSITE-2: 30 MILLION

FIGURE 5-12
COST VERSUS DIET SELENIUM CONCENTRATION
FOR ALTERNATIVE CLEANUP PLANS

CH2M HILL



* Percentages refer to chance of average avian diet being less than Y-axis value.

FIGURE 5-13

COSTS OF ALTERNATIVE CLEANUP PLANS VERSUS SOIL & DIET SELENIUM

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APPENDIX A

Appendix A
Kesterson Reservoir
Wildlife Species List

Common Name[a]	Scientific Name
Mammals	
Virginia opossum	Didelphis virginia
Ornate shrew	Sorex ornatus
Marsh shrew	S. bendirii
Broad-footed mole	Scapanus latimanus
Bat species	Myotis spp., Lasiurus spp.
	Eptesicus spp.
	Pipistrellus spp.
Desert cottontail	Sylvilagus audubonii
Black-tailed hare	Lepus californicus
California ground squirrel	Spermophilus beecheyi
Botta's pocket gopher	Thomomys bottae
San Joaquin pocket mouse	Perognathus inornatus inornatus
Heermann's kangaroo rat	Dipodomys heermanni
Fresno kangaroo rat	D. nitratoides exilis
Short-nosed kangaroo rat	D. n. brevinasus
Western harvest mouse	Reithrodontomys megalotis
Deer mouse	Peromyscus maniculatus
Muskrat	Ondatra zibethicus
California vole	Microtus californicus
House mouse	Mus musculus
Coyote	Canis latrans
San Joaquin kit fox	Vulpes macrotis mutica
Raccoon	Procyon lotor
Long-tailed weasel	Mustela frenata
Mink	M. vison
Badger	Taxidea taxus
Western spotted skunk	Spilogale gracilis
Striped skunk	Mephitis mephitis
Birds	
Pied-billed grebe	Podilymbus podiceps
Horned grebe	Podiceps auritus
Eared grebe	P. nigricollis
Western grebe	Aechmophorus occidentalis
American white pelican	Pelecanus erythrorhynchos
Double-crested cormorant	Phalacrocorax auritus
American bittern	Botaurus lentiginosus
Great blue heron	Ardea herodias
Great egret	Casmerodius albus
Snowy egret	Egretta thula
Cattle egret	Bubulcus ibis

Common Name[a]	Scientific Name
Birds (continued)	
Green-backed heron	Butorides striatus
Black-crowned night-heron	Nycticorax nycticorax
White-faced ibis	Plegadis chihi
Tundra swan	Cygnus columbianus
Greater white-fronted goose	Anser albifrons
Snow goose	Chen caerulescens
Ross' goose	C. rossii
Canada goose	Branta canadensis
Green-winged teal	Anas crecca
Mallard	A. platyrhynchos
Northern pintail	A. acuta
Blue-winged teal	A. discors
Cinnamon teal	A. cyanoptera
Northern shoveler	A. clypeata
Gadwall	A. strepera
Eurasian wigeon	A. penelope
American wigeon	A. americana
Canvasback	Aythya valisineria
Redhead	A. americana
Ring-necked duck	A. collaris
Greater scaup	A. marila
Lesser scaup	A. affinis
Common goldeneye	Bucephala clangula
Bufflehead	B. albeola
Hooded merganser	Lophodytes cucullatus
Common merganser	Mergus merganser
Ruddy duck	Oxyura jamaicensis
Turkey vulture	Cathartes aura
Osprey	Pandion haliaetus
Black-shouldered kite	Elanus caeruleus
Bald eagle	Haliaeetus leucocephalus
Northern harrier	Circus cyaneus
Cooper's hawk	Accipiter cooperii
Sharp-shinned hawk	A. striatus
Swainson's hawk	B. swainsoni
Red-tailed hawk	B. jamaicensis
Ferruginous hawk	B. regalis
Rough-legged hawk	B. lagopus
Golden eagle	Aquila chrysaetos
American kestrel	Falco sparverius
Prairie falcon	F. mexicanus
Ring-necked pheasant	Phasianus colchicus
Virginia rail	Rallus limicola
Sora	Porzana carolina
Common moorhen	Gallinula chloropus

Appendix A
(Continued)

Common Name[a]	Scientific Name
Birds (continued)	
American coot	*Fulica americana*
Sandhill crane	*Grus canadensis*
Black-bellied plover	*Pluvialis squatarola*
Snowy plover	*Charadrius alexandrinus*
Semipalmated plover	*C. semipalmatus*
Killdeer	*C. vociferus*
Black-necked stilt	*Himantopus mexicanus*
American avocet	*Recurvirostra americana*
Greater yellowlegs	*Tringa melanoleuca*
Lesser yellowlegs	*T. flavipes*
Willet	*Catoptrophorus semipalmatus*
Spotted sandpiper	*Actitus macularia*
Whimbrel	*Numenius phaeopus*
Long-billed curlew	*N. americanus*
Marbled godwit	*Limosa fedoa*
Western sandpiper	*Calidris mauri*
Least sandpiper	*C. minutilla*
Baird's sandpiper	*C. bairdii*
Pectoral sandpiper	*C. melanotos*
Dunlin	*C. alpina*
Short-billed dowitcher	*Limnodromus griseus*
Long-billed dowitcher	*L. scolopaceus*
Common snipe	*Gallinago gallinago*
Wilson's phalarope	*Phalaropus tricolor*
Red-necked phalarope	*P. fulicaria*
Bonaparte's gull	*Larus philadelphia*
Ring-billed gull	*L. delawarensis*
California gull	*L. californicus*
Herring gull	*L. argentatus*
Caspian tern	*Sterna caspia*
Forster's tern	*S. forsteri*
Black tern	*Chidonias niger*
Rock dove	*Columba livia*
Mourning dove	*Zenaida macroura*
Common barn-owl	*Tyto alba*
Great horned owl	*Bubo virginianus*
Burrowing owl	*Athene cunicularia*
Short-eared owl	*Asio flammeus*
Lesser nighthawk	*Chordeiles acutipennis*
Belted kingfisher	*Ceryle alcyon*
Northern flicker	*Colaptes auratus*
Black phoebe	*Sayornis nigricans*
Say's phoebe	*S. saya*
Western kingbird	*Tyrannus verticalis*
Horned lark	*Eremophila alpestris*
Tree swallow	*Tachycineta bicolor*

Appendix A
(Continued)

Common Name[a]	Scientific Name
Birds (continued)	
Violet-green swallow	*T. thalassina*
Northern rough-winged swallow	*Stelgidopteryx serripennis*
Cliff swallow	*Hirundo pyrrhonota*
Barn swallow	*H. rustica*
Yellow-billed magpie	*Pica nuttailli*
American crow	*Corvus brachrhynchos*
Marsh wren	*Cistothorus palustris*
American robin	*Turdus migratorius*
Water pipit	*Anthus spinoletta*
Loggerhead shrike	*Lanius ludovicianus*
European starling	*Sturnus vulgaris*
Yellow-rumped warbler	*Dendroica coronata*
Common yellowthroat	*Geothlypis trichas*
Lark sparrow	*Chondestes grammacus*
Savannah sparrow	*Passerculus sandwichensis*
Grasshopper sparrow	*Ammodramus savannarum*
Song sparrow	*Melospiza melodia*
Lincoln's sparrow	*M. lincolnii*
Golden-crowned sparrow	*Zonotrichia atricapilla*
White-crowned sparrow	*Z. leucophrys*
Dark-eyed junco	*Junco hyemalis*
Red-winged blackbird	*Agelaius phoeniceus*
Tricolored blackbird	*A. tricolor*
Western meadowlark	*Sturnella neglecta*
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*
Brewer's blackbird	*Euphagus cyanocephalus*
Brown-headed cowbird	*Molothrus ater*
House finch	*Carpodacus mexicanus*
House sparrow	*Passer domesticus*

[a]Nomenclature follows Laudenslayer and Grenfell (1983).